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Design of Self-Isolated Two Port Circular Patch Antenna for 5G Wireless Application

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Abstract

For fifth-generation (5G) and fourth-generation (4G) mobile communication, a multiple-input multiple-output (MIMO) antenna system is proposed. This research provides a self-isolated circular patch antenna element with compact dimensions of 90 × 80 × 1.6 mm^3. The proposed antenna structure consists of a two-port configuration with different rotation characteristics such as 0^0 (Co-planar), 90^0 (Rotated), 180^0 (Inverted). The proposed antenna design facilitates dual-band operation at 3.4 and 3.9 GHz. It offers good isolation between -30.64dB to -41.07dB and radiation efficiency greater than 85% without utilizing any additional isolation or decoupling components. The proposed antenna used FR4 epoxy substrate with thickness 1.6mm and simulated using HFSS software.

Keywords: 5G communication, circular patch, rotation characteristics, self-isolated, two-port.

1. Introduction

With the advancement of semiconductor technology, a number of wireless communication technologies have been introduced to satisfy the expanding needs of customers. For greater Quality of Service (QoS), which has prompted a pressing need to develop effective RF systems [1].

Reliable infrastructure that can solve these issues is required to meet the needs for increased data rates and QoS, which puts RF engineers under constant pressure to provide solutions. The main replacement for the present 3G technology is Long Term Evolution (LTE), sometimes known as 4G technology.

Systems built on LTE/4G are mostly focused

1. The capacity and speeds of data and voice services might be increased by deploying a new breed of RF systems that would be based on the existing GPRS and UMTS and combine the advantages of the two technologies.
2. Offer services with improved voice and data quality.
3. Increase the data rates for both the uplink and downlink.
4. Expand the channel's bandwidth.
5. Put more of an emphasis on serving more consumers per cell [2].

However, 5G technology promises to offer more data per unit of time and lower latency than 4G technology.

Since 2G to 4G mobile technology has already been implemented on the wireless mobile network, using higher frequency bands with wider operating bands will allow for higher data sending rates. A new eight-port dual-polarized MIMO antenna array has been created for a 5G smartphone [3]. The widespread use of 2G, 3G, and 4G devices, as well as the development of mobile phone antennas with small form factors and extensive operating bands, has increased the appeal of wireless communication systems for use in real-world scenarios [4]. By using multiple paths for data transmission and reception, MIMO antenna can increase wireless system capacity [5].

This paper analyzes a self-isolated two port circular patch antenna with coplanar, rotated and inverted rotation characteristics. Simulation of antenna evaluated, considering important metrics such as return loss, isolation, gain, and efficiency and antenna structures.

The remaining sections are arranged as follows: section 2 presents a review of the related works. Section 3 carries antenna configuration in which 3.1 carries design of basic 5G antenna and the results of a basic 5G antenna simulation are shown in part 3.2 and 3.3 shows simulated results of circular configuration for two port with different rotation characteristics. Section 4 describes comparison of various rotation characteristics of circular patch antenna configurations. Section 5 deals with the conclusion.

2. Related Works

The modern mobile user expects more dependable service and better data rates. Multi-input multi-output (MIMO) operation is known to result in a much greater channel capacity for improved data throughput. The MIMO operation can achieve substantially larger channel capacity by adding additional antennas. Massive MIMO thus appears to be quite promising for mobile communications in the future. However, because to the Smartphone's extremely constrained size, it is fantastic to create the challenge to incorporate more antennas inside [6]. Several short-range wireless personal area network (WPAN) applications for modern wireless consumer electronics goods demand a higher data rate and throughput [7]. For many years, there has been a lot of research interest in multiple antenna technologies, and they have progressively entered the realm of widespread communication systems [8]. Basic mobile voice communication was handled using analog transmission in the first generation (1G). The early data services and improved spectrum efficiency of the 2G networks were made possible by the adoption of digitally upgraded multiple access methods. Technologies improved streaming capability for both video and audio in 3G. Additionally, long-term evolution (LTE) was created to provide fully functional 4G mobile internet and an upgrade to current 3G networks [9]. Due to the growing need for data rates in online gaming, video streaming, and the transfer of large data files, wireless communication technologies have greatly improved during the past ten years. MIMO technology is essential for wireless technology because it may boost diversity and increase system capacity without requiring more power or bandwidth. The 4G MIMO antenna system is based on 4-element wideband monopoles, whereas the 5G MIMO antenna system is based on 2-element linear linked arrays [10]. For many years, there has been a lot of research interest in multiple antenna technologies, and they have progressively found their way into communication systems used by the general public [11]. Today, everyone in the globe is aware of the importance of wireless communication. Numerous tactics and procedures have been proposed in an effort to improve communication. Among these methods, smart antennas are a popular study area [12]. By minimizing the loss brought on by polarization mismatch, circular polarized antennas can prevent antenna orientation [13]. Multiple antenna technologies have attracted large research interest for several decades and have gradually made their way into mainstream communication systems [14]. Table I shows the comparison of latest literature with our proposed work.

Table I: Comparison of latest literature with our proposed work

Ref. No	Dimensions	Frequency range (GHz)	Isolation (dB)	Peak Gain (dB)	ECC	Substrate Material	Proposed Technique
[15]	158×77×0.38	1.9-2.6 GHz band for 4G and 27-40 GHz band 5G	> -14 dB	3.6 dBi for the 4G at 2 GHz and 9 dBi for the 5G at 38 GHz	Not mentioned	Rogers RT/duroid 5880	open-ended slot antenna

[16]	25×12 ×0.38	1.8-2.6 GHz band for 4G 25-40 GHz band 5G	> -17dB	7.2	Not mentioned	Rogers RT/duroid 5880	Integrated open-ended slot antenna
[17]	50×50×1.6	2.51 GHz to 2.83 GHz	> -30dB	4.9dBi to 5.3dBi across the operating band	0.003	FR-4	cylindrical dielectric resonator (CDR) based MIMO
[18]	75 × 150×1.6	2.5–2.7 GHz (long-term evolution (LTE) 2600), 3.45–3.8 GHz (LTE bands 42/43), and 5.00–5.45 GHz (LTE band 46)	> -17dB	2.5–2.8 dB	0.002	FR-4	multi-band slot antenna array
Our work	90×150×1.6	-22.61 and -41.88 dB at 3.4 and 3.9 GHz resp.	> -30dB	2.66 dB and 4.80 dB at 3.4 and 3.9 GHz resp.	0.0002 and 0.00004	FR-4	Microstrip antenna

3. Antenna Configuration

3.1 Design of circular patch antenna

Rectangular, square, and circular forms are most frequently used for microstrip patch antennas because they are simple to construct and analyze, have lower feed radiations, greater bandwidths, and have symmetrical radiation properties. Figure 1 shows a microstrip patch antenna with radiating patch on top that is fed by a microstrip feedline and a full ground plane at the bottom. Two slots in the radiating patch of dimension 12×2 mm^2 help improve the bandwidth of the proposed antenna. The radiating patch of the antenna that is being exhibited is circular in shape and has a radius of 'a'.

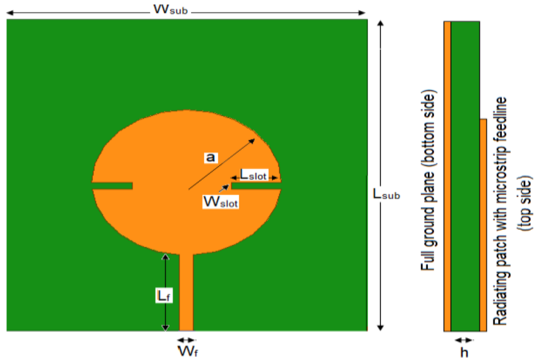


Figure 1. Antenna configuration of basic 5G antenna

The following equations from [8] are used to compute the antenna's dimensions. The antenna is made to function at resonance frequency f_r, which is 3.45 GHz. Equation (1) is used to compute the circular patch antenna's radius 'a':

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

With

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

Where h = 0.16 cm (1.6mm) represents the substrate's height or thickness, fr = 3.45 GHz represents the antenna resonance frequency, and ε_r = 4.4 represents the FR4 epoxy substrate's dielectric constant. According to equations (1) and (2), the circular patch's theoretical radius 'a' is 33.15mm. A microstrip feed line was selected as the feedline because it is simple to design, model, and manufacture. The circular patch's radius is approximately 75% of the feed line’s length. The antenna impedance affects feed-width. The antenna is assumed to have a 50 Ω impedance. This is so because the majority of RF equipment has an impedance that falls between 50 Ω and 75 Ω. In order to prevent mismatch losses, the antenna must be exactly matched when these devices are linked to it. Equations given as follows from [14] can be used to compute the feed-width:

For W/h ≤ 1:

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left\{\left(1 + 12\frac{h}{W_f}\right)^{-0.5} + 0.04\left(1 - \frac{W_f}{h}\right)^2\right\} \quad ...(3)$$

$$Z_c = \frac{\eta}{2\pi\sqrt{\varepsilon_{re}}}\ln\left(\frac{8h}{W_f} + 0.25\frac{W_f}{h}\right) \quad ...(4)$$

Where η = 120π Ω is free-space wave impedance

For W/h ≥ 1:

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W_f}\right)^{-0.5} \quad ...(5)$$

$$Z_c = \frac{\eta}{\sqrt{\varepsilon_{re}}}\left\{\frac{W_f}{h} + 1.393 + 0.677\ln\left(\frac{W_f}{h} + 1.444\right)\right\}^{-1} \quad ...(6)$$

Most of the time, W/h is greater than 1. We therefore use equations (5) and (6). Wf (feed width) has a theoretical value of 3.2mm at Zc = 50 Ω. Table II shows antenna parameter theoretical and optimized value.

Table II: Antenna dimensions (Theoretical and Optimised)

Antenna Parameter	**Antenna Parameter Value**	
	Theoretical value	***Optimized value***
Radius 'a'	33.15 mm	21.0 mm
Feedline length, L_f	24.80 mm	24.0 mm
Feedline width, W_f	3.200 mm	3.00 mm
Substrate length, L_{sub}	78.00 mm	90.0 mm
Substrate width, W_{sub}	73.15 mm	80.0 mm
Substrate thickness, h	1.60 mm	1.60 mm
Slot length, L_{slot}	-	12.0 mm
Slot width, W_{slot}	-	2.0 m

3.2 Simulated results of circular patch antenna

The antenna designed using HFSS software has obtained simulated return loss as shown in Figure 2. The antenna operates at two frequencies: 3.4 GHz and 3.9 GHz. The proposed antenna has -10dB return loss bandwidths of 280 MHz over the 3.31 – 3.59 GHz frequency range at the first fundamental frequency of 3.4 GHz and 300 MHz over the 3.8 – 4.10 GHz frequency range at the second resonant frequency of 4.14 GHz.

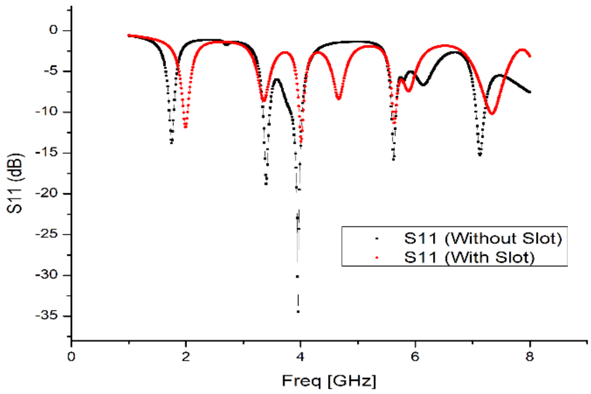


Figure 2. Simulated return loss with and without slot in radiating patch

Return loss results shows that by adding a slot in the radiating patch improves resonance and bandwidth at all operating frequency

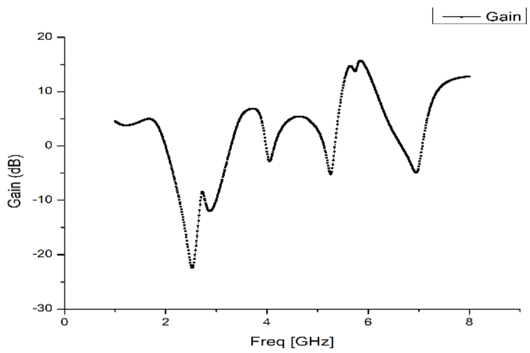


Figure 3. Simulated gain characteristics of basic 5G antenna

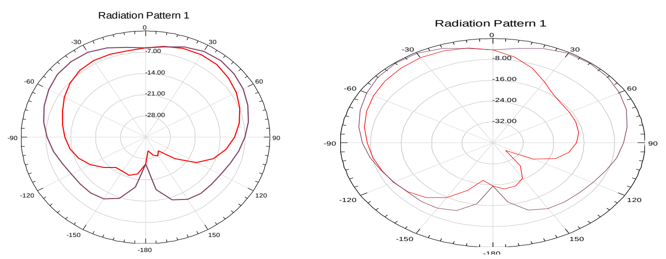


Figure 4. Simulated radiation characteristics at 3.4 GHz and 3.9 GHz respectively

The simulated gain characteristics of the proposed antenna are shown in Figure 3. The antenna offers a gain of 3.39 dB and 4.62 dB respectively at 3.4 GHz and 3.9 GHz. The proposed antenna's radiation properties are shown in Figure 4. The antenna offers directional characteristics along both E and H planes.

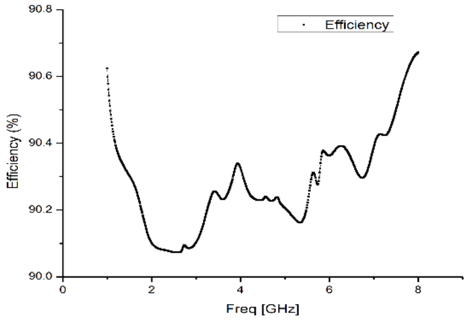


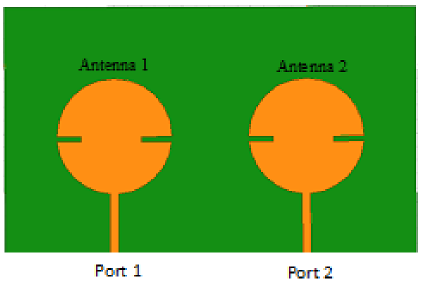
Figure 5. Simulated radiation efficiency characteristics of basic 5G antenna

The antenna offers overall radiation efficiency of about 90% across all operating frequencies as shown in Figure 5.

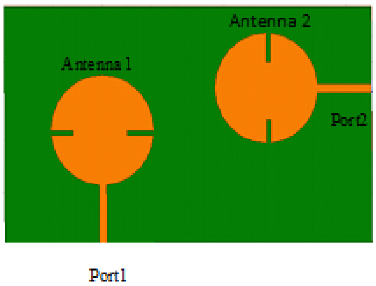
3.3 Simulated results of circular configuration for two port with different rotation characteristics

A self-isolated circular patch antenna element with a two port antenna configuration with different rotation characteristics is presented in this section. Figure 6. Shows circular patch configuration for two port rotated antenna with

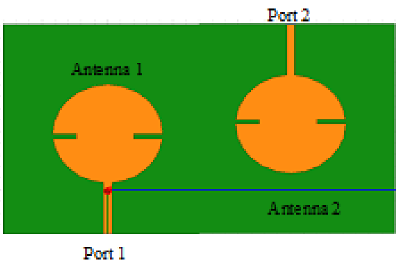
a) 0^0 (Co-planar) b) 90^0 (Rotated) c) 180^0 (Inverted). The antennas have been placed at a distance of d = 29mm.



(a)



(b)



(c)

Figure 6. Circular configuration for two port (a) 0^0 (Co-planar) (b) 90^0 (Rotated) (c) 180^0 (Inverted)

The proposed two port circular patch antenna configuration facilitates operation at 3.4 GHz and 3.9 GHz. The simulated S_{11} and S_{22} characteristics are as shown in Figure 7. In order to prevent interference between transmitting and receiving antennas when situated near together, antennas are supposed to display high degree isolation or mutual coupling [19]-[21]. The degree of mutual coupling is represented by S_{12} and S_{21} characteristics as shown in Figure 8. The proposed two port circular patch antenna configuration offers mutual coupling of -32.66 and –30.64 dB at 3.4 and 3.9 GHz respectively.

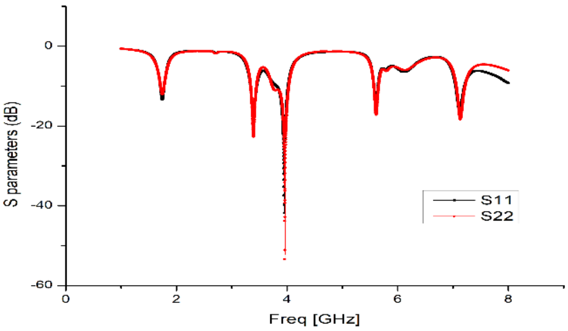


Figure 7. Simulated S_{11} and S_{22} characteristics of two port circular patch antenna configuration

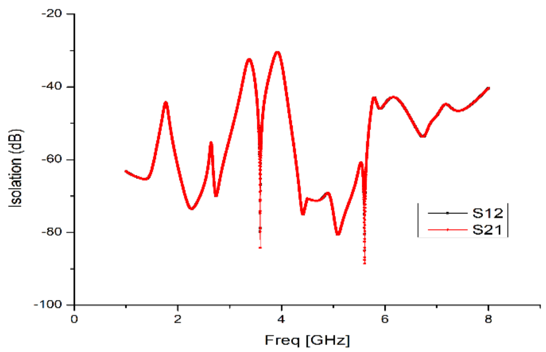


Figure 8. Simulated S_{12} and S_{21} characteristics of two port circular patch antenna configuration

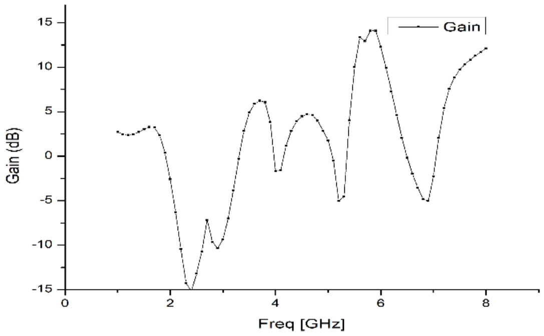


Figure 9. Simulated gain characteristics of the two port circular patch antenna configuration

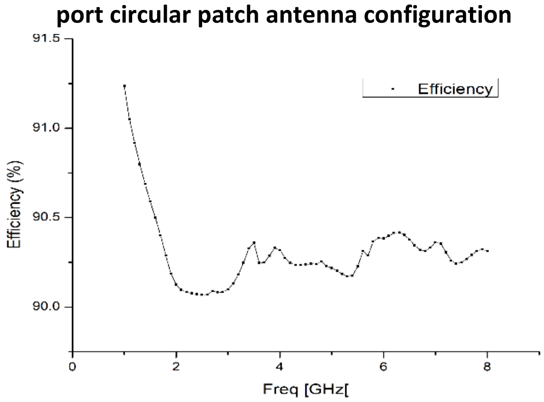


Figure 10. Simulated radiation efficiency characteristics of the two port circular patch antenna configuration

Figure 9 shows the simulated gain characteristics of the two port circular patch antenna. The antenna offers a gain of 2.66 dB and 4.80 dB respectively at 3.4 GHz and 3.9 GHz. Figure 10 shows the radiation efficiency characteristics of the two port circular patch antenna. The antenna offers overall radiation efficiency of about 90% across all operating frequencies.

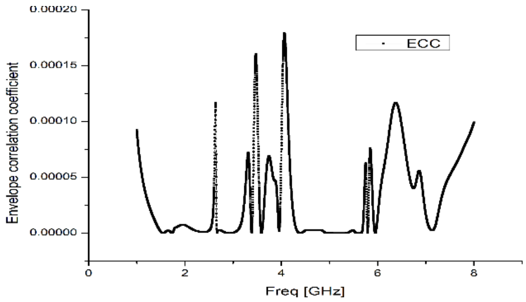


Figure 11. ECC characteristics of the two port antenna configuration

An essential metric for evaluating a MIMO communication system's performance is the envelope correlation coefficient. The Envelope Correlation Coefficient indicates the degree of independence between the radiation patterns of two antennas. Figure 11 shows two port antenna configuration with less than 0 Envelope Correlation Coefficient characteristics

4. Simulation results and analysis

In this section Table III presents comparative analysis of various two port circular antenna configurations.

Table III: Comparison of rotation characteristics

Antenna Parameter	**Antenna Rotation Angle**		
	0^0 (Co-planar)	***90^0 (Rotated)***	***180^0 (Inverted)***
Antenna size	90×150mm^2	90×150mm^2	90×150mm^2
Spacing between antennas (patch to patch)	29mm	29mm	29mm

Return loss (S_{11}, S_{22})	-18.87 and -14.44 dB at 3.4 and 3.9 GHz resp.	-19.13 and -28.67 dB at 3.4 and 3.9 GHz resp.	-22.61 and -41.88 dB at 3.4 and 3.9 GHz resp.
Isolation (S_{12}, S_{21})	-32.80 and –32.57 dB at 3.4 and 3.9 GHz resp.	-33.96 and -41.07 dB at 3.4 and 3.9 GHz resp.	-32.66 and -30.64 dB at 3.4 and 3.9 GHz resp.
Gain	2.84 dB and 3.79 dB at 3.4 and 3.9 GHz resp.	0.86 dB and 1.21 dB at 3.4 and 3.9 GHz resp.	2.66 dB and 4.80 dB at 3.4 and 3.9 GHz resp.
Efficiency	> 90%	>85%	> 90%
Antenna structure	As shown in Figure 6(a)	As shown in Figure 6(b)	As shown in Figure (c)

5. Conclusions and Future Work

In this paper, the design of a self-isolated antenna element with a two port circular patch antenna configuration is analyzed. The proposed antenna design facilitates dual-band operation at 3.4 and 3.9 GHz. It offers a good amount of isolation between -30.64dB to -41.07dB with less than 0 Envelope Correlation Coefficient characteristics for various rotation characteristics such as coplanar, rotated and inverted. For inverted rotation characteristics, the proposed antenna arrangement offers good gain of 2.66 dB and 4.80 dB and mutual coupling of -32.66 and –30.64 dB at 3.4 and 3.9 GHz, respectively. The antenna offers efficiency greater than 85% in all rotation characteristics making it suitable for 5G wireless applications. Further to reduce the size of antenna implement EBG (electronic bandgap) while still maintaining the mutual coupling tradeoff.

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