Design of self-isolated 2 × 2 MIMO antenna for 5G wireless application

[1]Ms. Yogita Kute, [2]Dr. R. P. Labade
[1,2]*Department of Electronics and Telecommunication Engineering Amrutvahini College of Engineering*
Sangamner, India

***Abstract*— In this research project, we have proposed a self-isolated antenna element with compact dimensions for the fifth generation (5G) multiple-input multiple-output (MIMO) wireless applications. The proposed antenna structure consists of a 2 × 2 MIMO configuration that offers good isolation and efficiency without using any additional isolation elements or decoupling methods. The proposed antenna is simulated using HFSS CEM software and fabricated on an FR4 glass epoxy substrate and measured. The simulated and measured results are in good agreement with each other.**

Keywords—5G communication, MIMO configuration, self-isolated

I.INTRODUCTION

Over the years with advancements in semiconductor technology, several advanced wireless communication technologies have been introduced to suffix the increasing demands of the customers for better Quality of Service (QoS), which has spurred up an urgent need to design efficient RF systems. With the continuous development of communication standards (Figure 1) from the early-based systems to the high-speed data and voice services using 3GPP configurations, customers' access to data has seen a drastic.

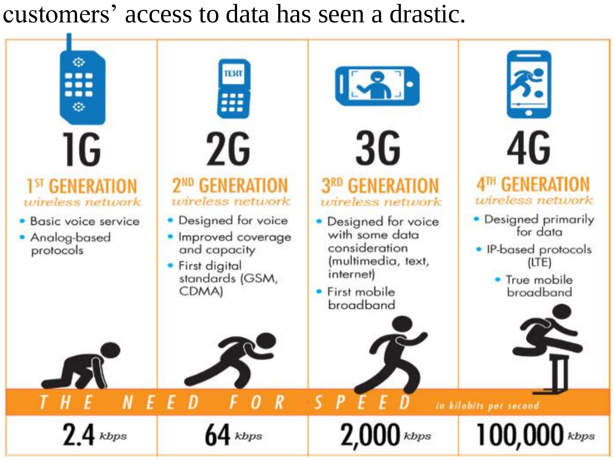

Fig. 1 Evolution of 1G to 4G technology

To meet these demands of higher data rates and QoS, reliable infrastructure capable of addressing these challenges is needed, thereby keeping RF engineers under constant pressure to meet these challenges. Long Term Evolution (LTE) or 4G technology is the key successor to the current 3G technology.

LTE/4G-based systems primarily focus

1. Increasing the capacity and speeds of data and voice services by deploying a different breed of RF Systems which would be based on the existing GPRS and UMTS, and combining the advantages of the said technologies.
2. Provide enhanced voice and data quality services.
3. Provide improved Uplink and Downlink data rates.
4. Increase the channel capacity.
5. Focus on providing services to more number of users in a cell.
6. Use the Multiple Input and Multiple Output (MIMO) configuration to the fullest to meet the demands of the customers.

However 5G, technology promises to provide higher bandwidth than 4G technology and smaller latency as compared to 4G technology.

Table 1. 1G to 5G Comparison

Tech/ Parameter	1G	2G	3G	4G	5G
Period	1980 – 1990	1990 – 2000	2000 – 2010	2010 – 2020	2020 - 2030
Bandwidth	2.4Kbps	64Kbps	144-kbps to 2Mbps	100 Mbps to 1Gbps	>1Gbps
Frequency range	Analog signal (30 KHz)	1.8GHz (digital)	1.6 – 2.0 GHz	2 – 8 GHz	3 – 300 GHz
Services offered	Mobile telephony	Digital voice, SMS	Integrated high-quality audio,	Dynamic information	Dynamic information access,

			video, and data	access, variable devices	variable devices with AI capabilities
Switching	Circuit	Circuit/Circuit for access and air interface	Packet except for air interface	All packet	All packet
Core Network	PSTN	PSTN	Packet	Internet	Internet

As the wireless mobile network has already migrated from 2G to 4G mobile technology higher data transmitting rate can be acquired by utilizing higher frequency bands with wide operating bands. New eight-port dual-polarized multiple-input multiple-output (MIMO) antenna array design for 5G Smartphone [1]. The rapid development of wireless communication systems, especially the widespread use of 2G/3G/4G devices and mobile phone antennas with small sizes and wide operating bands, are more attractive for practical applications [2]. MIMO antenna can enhance wireless system capacity by multi-path data transmission and reception [3].

Today's mobile user wants faster data speeds and more reliable service. It is known that multi-input multi-output (MIMO) operation can lead to a much higher channel capacity for enhanced data throughput. When more antennas are included in the MIMO operation, much higher channel capacity can be obtained. So, massive MIMO looks very promising for future mobile communications. However, owing to the very limited space in the Smartphone, it is great to design the challenge to embed more antennas inside [4]. Recent wireless consumer electronics devices need a higher data rate and throughput in numerous short-range wireless personal area network (WPAN) applications [5]. Multiple antenna technologies have attracted large research interest for several decades and have gradually made their way into mainstream communication systems [6]. The first generation (1G) used the analog transmission to fulfill basic mobile voice transmission. The 2G systems used digitally enhanced multiple access technologies leading toward early data services and enhanced spectral efficiency. In 3G, technologies enhanced improvements within video and audio streaming capabilities. Also developed the long-term evolution (LTE) to offer a complete 4G capable mobile broadband and an upgrade to existing 3G networks [7]. Wireless communication systems have improved a lot in the last decade due to the high demand for data rates in video streaming, online gaming, and transferring huge data files. Multiple-input multiple-output (MIMO) technology is very crucial for wireless technology because it can increase system capacity and improve diversity without increasing the power or bandwidth. The 4G MIMO antenna system is based on 4-element wideband monopoles, while the 5G one is based on 2-element linear connected arrays [8].

II.ANTENNA CONFIGURATION OF BASIC 5G ANTENNA

A. Design of basic 5G antenna

For now, India has earmarked 3300-3600 MHZ bands for 5G. But Indian telecom operators use spectrum in 1800, 2100, and 2300 MHz bands as well as those in the 800 and 900 MHz bands to currently offer 5G. A microstrip patch antenna can be of any shape but rectangular, square, and circular-shaped microstrip patch antennas are widely used as they are simple to design and analyze, reduce feed radiations, have higher bandwidths, and provide symmetrical radiation characteristics.

A microstrip patch antenna has a radiating patch on the top side which is fed with a microstrip feedline and a full ground plane on the bottom side. Two slots in the radiating patch of dimension 12×2 mm^2 help improve the bandwidth of the proposed antenna. The presented antenna consists of a radiating patch circular in nature and having a radius 'a'. The dimensions of the antenna are calculated by the following equations proposed in [6]. The antenna is designed to operate at the resonant frequency f_r = 3.45 GHz. The radius 'a' of the circular patch antenna is calculated using equation (1):

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

with

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

Where h = 0.16 cm (1.6mm) is the height of substrate/ thickness of the substrate, f_r = 3.45 GHz is the antenna resonant frequency, and ε_r = 4.4 is the dielectric constant of FR4 epoxy substrate. Following equations (1) and (2), the theoretical value of radius 'a' of the circular patch is 33.15mm. The feedline chosen is a microstrip feed line as it is easy to design, model, and fabricate. The feedline length is approximately 75% of the radius of the circular patch. The feed-width depends on the antenna impedance. The antenna impedance is considered as 50 Ω. This is because most RF devices have characteristics impedance of either 50 Ω or 75 Ω. Hence, when these devices are connected to the antenna; the antenna must be perfectly matched to avoid mismatch losses. The feed-width can be calculated using equations presented in given as:

For $W/h \leq 1$:

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

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

Where $\eta = 120\pi\ \Omega$ is the wave impedance in free space

For $W/h \geq 1$:

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

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

In most cases, W/h is usually greater than 1. Hence, we use equations 5 and 6. With $Z_c = 50\ \Omega$, theoretical value of W_f (feed width) = 3.2mm.

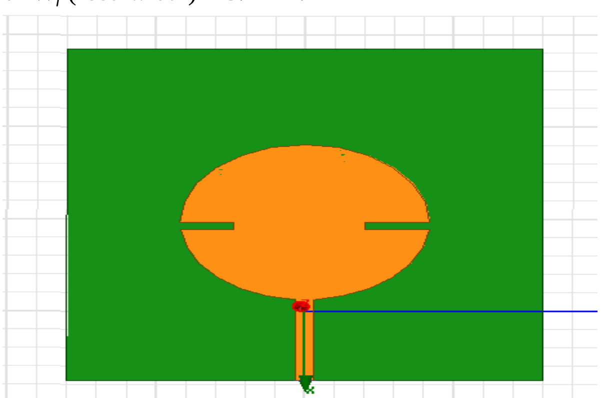

Fig. 2 Antena configuration of basic 5G antenna

TABLE II. ANTENNA DIMENSIONS (THEORETICAL AND OPTIMIZED)

Antenna Parameter	Antenna Parameter Value	
	Theoretical value	*Optimized value*
Radius 'a'	33.15 mm	32.0 mm
Feedline length, L_f	24.8 mm	20.5 mm
Feedline width, W_f	3.20 mm	3.50 mm
Substrate length, L_{sub}	78.0 mm	84.0 mm
Substrate width, W_{sub}	53.5 mm	72.5 mm
Substrate thickness, h	1.60 mm	1.60 mm

B. Simulated results of basic 5G antenna

The antenna designed using HFSS CEM software has obtained simulated return loss as shown in Fig 3. 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.

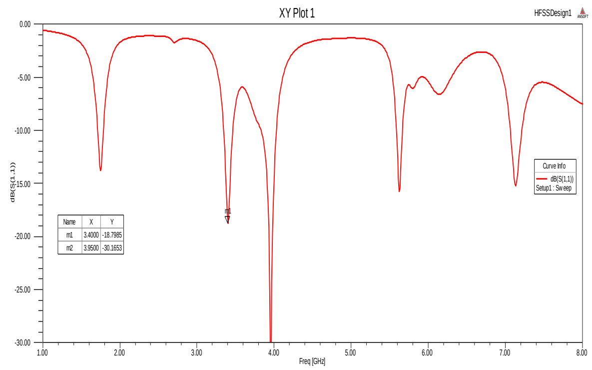

Fig. 3 Simulated return loss

Fig. 4 Simulated gain characteristics

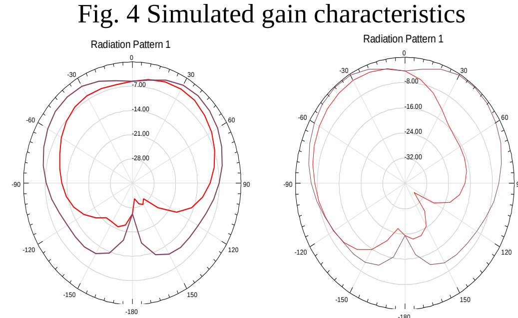

Fig. 5 Simulated radiation characteristics at 3.4 GHz and 3.9 GHz respectively

Fig. 4 shows the simulated gain characteristics of the proposed antenna. The antenna offers a gain of 3.39 dB and 4.62 dB respectively at 3.4 GHz and 3.9 GHz. Fig. 5 shows the radiation characteristics of the proposed antenna. The antenna offers directional characteristics along both E and H planes. The antenna offers overall radiation efficiency of about 90% across all operating frequencies as shown in Fig. 6.

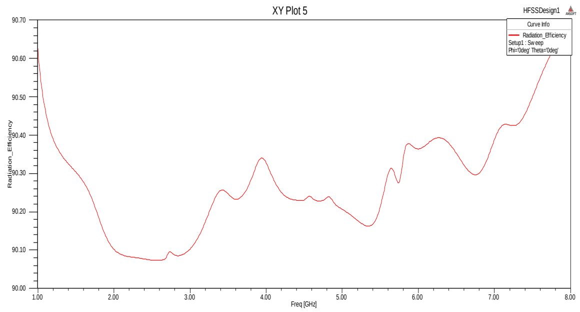

Fig. 6 Simulated radiation efficiency characteristics

III.2 × 2 MIMO ANTENNA CONFIGURATION

A self-isolated antenna element with a 2 × 2 MIMO antenna configuration is presented in this section. Two basic antennas presented in the previous section in an inverted configuration is proposed to obtain the 2 × 2 MIMO antenna configuration. The antennas have been placed at a distance of d = 70mm from the center of the patch as shown in Fig. 7.

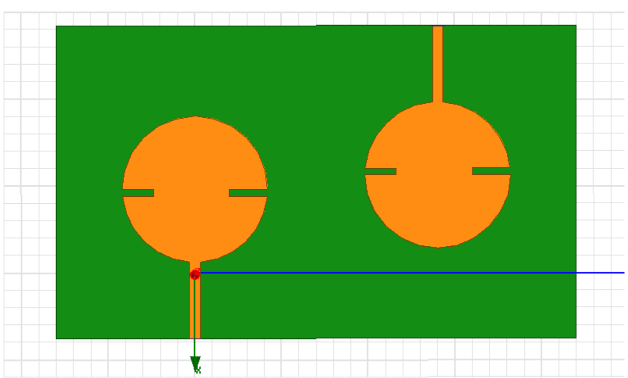

Fig. 7 Self-isolated antenna element with 2 × 2 MIMO antenna configuration

The proposed 2 × 2 MIMO antenna configuration facilitates operation at 3.4 GHz and 3.9 GHz. The simulated S_{11} and S_{22} characteristics are as shown in Fig. 8. MIMO antennas are expected to exhibit high degree isolation or mutual coupling to avoid cross-talk between transmitting and receiving antennas when placed in close vicinity. The degree of mutual coupling is represented by S_{12} and S_{21} characteristics as shown in Fig. 8. The proposed 2 × 2 MIMO antenna configuration offers mutual coupling of -32.66 and –30.64 dB at 3.4 and 3.9 GHz respectively.

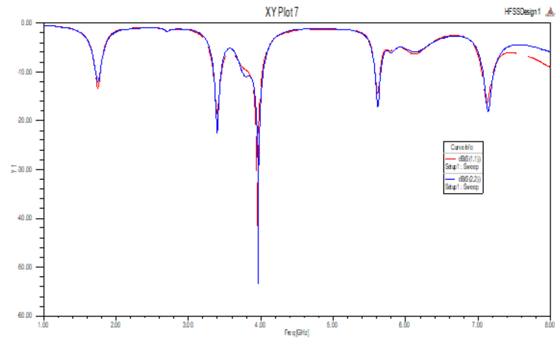

Fig. 8 Simulated S_{11} and S_{22} characteristics of 2 × 2 MIMO antenna configuration

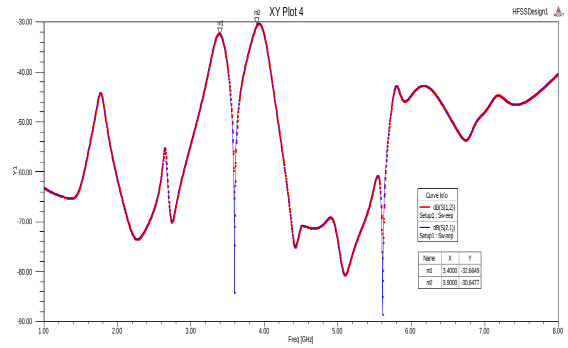

Fig. 9 Simulated S_{12} and S_{21} characteristics of 2 × 2 MIMO antenna configuration

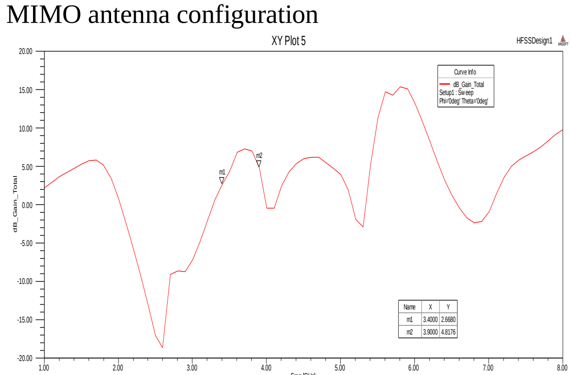

Fig. 10 Simulated gain characteristics of the 2 × 2 MIMO antenna configuration

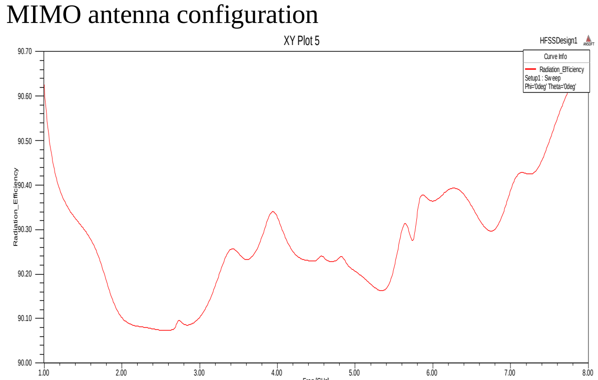

Fig. 11 Simulated radiation efficiency characteristics of the 2 × 2 MIMO antenna configuration

IV.CONCLUSION

In this paper, we have presented the design of a self-isolated antenna element with a 2 × 2 MIMO configuration that facilitates dual-band operation at 3.4 and 3.9 GHz. The proposed MIMO antenna configuration offers a good amount of isolation and reduced mutual coupling at the operational frequencies. The proposed antenna configuration has good gain, radiation, and efficiency characteristics making it suitable for 5G wireless applications.

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