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LTE and MMW 5G Integrated MIMO Antenna System

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Abstract

Objectives: In order to simultaneously operate several system services, minimise attenuation, and reduce atmospheric absorption at the mm-wave spectrum, design of 5G antenna systems with enhanced bandwidth and gain is very crucial. MIMO antennas are therefore essential in addressing the shortcomings of the current designs. An integrated 5G MIMO antenna system using mm-wave and LTE is proposed in this work. **Methods**: The suggested design includes LTE MIMO antenna with two elements and 5G MIMO system four elements including circular as well as rectangular ground plane faults. The suggested structure is created on a Rogers RO4350B substrate for its excellent frequency performance, low dielectric loss, good thermal conductivity, and high impedance stability. The geometrical size and dimensions of the substrate used is 75 mm 110 mm 0.76 mm.The proposed structure operates between 5.6 and 6.5 GHz and 26 and 30 GHz (5G mm-wave). Therefore, 5.9GHz and 27.5GHz are the resonance frequencies used in this work. **Findings:** CST Microwave Studio is used to model and simulate the proposed system. The LTE and 5G mm-wave antennas both achieved maximum gain of 9.9 and 9.7 dB at 27.5 GHz and 4.1 and 3.9 dB at 5.9 GHz, respectively. **Novelty:** Additionally, the investigation of the MIMO performance metrics reveals high field correlation performance across the operating bands as well as positive attributes. Performance parameters like Gain, reflection coefficient, radiation pattern, and envelope correlation coefficient confirms that the proposed method complies with the international standards. Therefore, it is clear that the suggested integrated MIMO antenna arrangement could be a competitor for future communication applications.

Keywords: Fourth-Generation (4G); Multiple Input Multiple Output (MIMO); MMW (mm-wave); Fifth-Generation (5G); Long-Term Evolution (LTE)

1 Introduction

Mobile communication has expanded rapidly during the last couple of decades. The need for wireless multimedia services like live TV, live movies, video conferencing, etc. has increased in modern times, which has sparked the development of wireless broadband technology. The Long Term Evolution is the subsequent-generation 4G technology for both Code CDMA and GSM cellular operators to satisfy consumer demand for high speed applications. The development of 5G which offers high data rates and more capacity of the channel than 4G/LTE is encouraged in response. The mm-Wave frequency range is a possible contender for new radio bands to expand the capacity for upcoming 5G mobile communication systems. At mm-wave frequencies, however, challenges such as attenuation in path loss and rising atmospheric absorption must be addressed. Thus, using a single antenna makes this more difficult. As a result, 5G antennas with increased bandwidth and gain are needed to operate numerous system services, reduce attenuation, and atmospheric absorption at the mm-wave spectrum parallelly. Therefore, MIMO antennas play vital role in overcoming the flaws of the existing designs. MIMO technique boosts data throughput and spectrum efficiency by using several antennas at the transmitting or receiving sections. The proliferation of wireless devices in recent years has significantly intensified attempts to create cutting-edge communication network standards. Additionally, a larger bandwidth and a greater data rate are required for the quick transfer of data wirelessly. Modern cellular standards have incorporated LTE, Broadband LTE and Commercial 4G Services to satisfy such high data requirements [1,2]. Following the introduction of LTE, industry and academic researchers began concentrating on mobile communications and next-generation broadband wireless for upcoming 5G wireless networks. Wireless equipment that complies with these 5G standards should be able to process large amounts of data quickly and efficiently. These systems have lately acquired popularity [3].

However, it is crucial to address obstacles at MMW frequencies, such as attenuation constrained to path loss and atmospheric absorptions. This is made more difficult by the usage of a single antenna. 5G antennas need to have a wider bandwidth and more gain to enable the concurrent working of numerous system services, reduce attenuation, and atmospheric absorption at the mm-wave spectrum. In LTE and forthcoming 5G applications, MIMO systems are essential because they enable many antennas to operate at simultaneously, improving channel capacity and enabling benefits like multi-Gbps speed and higher data rates. Multiple-Input many-Output (MIMO) technology makes use of many antennas on the transmitter and receiver to send more data concurrently. They are able to combine both SIMO and MISO technologies. Comparing the MIMO approach to single-input single-output (SISO) systems reveals some definite advantages. Spatial diversity significantly reduces fading, and compared to other MIMO systems, low power is needed. Antenna systems with a larger bandwidth and greater data rate are needed for the speedy wireless transfer of data.

The researchers have documented a number of works on Design of 4G/LTE and also 5G antennas [1,2,4]. One may have noticed that single-element or antenna arrays make up the majority of the suggested antenna solutions. Although using antenna arrays results in a high gain, it is found that the performance in terms of capacity is resulting poor. MIMO antenna deployment is therefore required to meet the capacity and throughput requirements. In-depth research has been done on MIMO antenna systems for 4G/LTE mobile communications. The 4G/LTE design and 5G antenna designs previously covered can be categorized as single-element, array, or MIMO antennas that use microwave or mm-wave frequencies [5,6]. For upcoming communication applications suitable for all ranges, combination of these two will be an effective solution. Due to the size limit and higher coupling currents between closely packed antennas designing such antennas is exceedingly difficult.

A defective ground structure (DGS) approach in MIMO antennas is the key answer to the current issues. As a result of variety of heterogeneous networks with quick advancements in radio access technologies, the creation and use of numerous antennas sparked interest in the wireless communication industry on a global scale. Mobile phones, USB dongles, and other portable terminals now support MIMO technology to enable high-speed data transmission. The creation of MIMO antennas was driven by the need for greater capacity and faster data rates across greater distances. [5] uses square-ring slots with two elements with each element covering 2.5-2.7 GHz, 3.45-3.8 GHz, and 5.00-5.45 GHz. The radiators' isolation has increased by 17 dB across all operational frequency bands. The FR-4 dielectric is used to implement the MIMO antenna, which has good S-parameters, efficiency, and radiation pattern coverage. [7] describes the design of a mm-wave antenna that is integrated with an LTE antenna and might be used in a contemporary smart phone. The antennas work between 700 and 960 MHz, 1710 and 2690 MHz, and 25 and 30 GHz with 60% total efficiency. The suggested layout demonstrates that sub-6 GHz antenna performance and display size may both be preserved while integrating 5G mm-wave antennas into 4G systems. In another study [8] class 7 LTE spectrum is covered by the integrated design of the 4G MIMO system while the 28 GHz mm Wave band is covered by the MMW 5G MIMO antenna offering 2.15 dBi gain. Conformal patch operates at 28 GHz with gain of 9 dBi and less than 35 dB of isolation.

In [9] integrated antenna system with DGS for millimeter-wave 5G wireless applications and handheld devices is presented that resulted in bandwidth of 24.4–29.3 GHz. Additionally, the working bandwidth of the 4G antenna array shows a peak gain of 5.41 dBi. The achieved peak gain for the 5G mm-wave setup is 10.29 dBi. Furthermore, the two antenna modules are effectively isolated from one another, enabling effective operation for two frequency bands with a single system. The exhibited structure has a number of benefits, including planar construction, high gain, wide bandwidth, and compactness [10]. A 4-element rectangular slotted patch antenna array for mm-wave frequency bands is presented in which ground plane is rendered defective. Gain obtained is 8.3 dBi. The observed antenna's strong MIMO performance validates the design's suitability for upcoming 5G wireless communication applications. For 5G mm-wave systems, [11] presented an array design for MIMO with two antenna arrays with a 90-degree shift and each with four components placed evenly. The antenna has a gain of 6.84 dB and efficiency of more than 85% for the frequency band of 37 GHz. A study in [12] provided a design for a MIMO antenna with four pairs of 3.6 GHz-resonating horizontally and vertically polarized resonators. Adjacent elements display good isolation while providing an acceptable radiation profile and adequate channel capacity. The MIMO antenna system used in the study in [13] operate at multiple frequencies 5.2 GHz for WLAN, 3.5 GHz for 5G, and 2.5 GHz for 4G LTE band applications comprising dual-band and triple-band monopole antennas while [14] presents an integrated MIMO antenna solution for Long LTE and mm-wave 5G wireless communication applications. A tri-band planar antenna array driven by a T-junction power divider and DGS was demonstrated in [15] and was intended to be included into future 5G mm-wave wireless communication applications that is proven to be suitable for portable wireless devices due to its compact, straightforward, and favorable radiation characteristics. In order to improve isolation between two neighboring input ports, a high-isolation balanced open-slot eight-antenna multi-input multi-output (MIMO) array operating in the 3.5 GHz range (3.4-3.6 GHz) is presented in [16]. The majority of the research centered on either LTE or 5G antenna design. Even if some researchers concentrated on integrated designs, the performance of an antenna in terms of gain, efficiency, and ECC is still difficult. In order to resolve the aforementioned issues, The LTE bands are supported by a two-element MIMO structure, and the mm-wave 5G frequency bands are supported by a 4-element MIMO configuration with both circular and rectangular ground plane defects. A new MIMO 4G/5G antenna design for smartphones has been reported [17]. It is made up of 2-element linear linked arrays for 5G and 4-element monopoles for 4G. A slot-based linked antenna array supporting 4G and 5G mm-wave wireless standards for a typical modern mobile phone is demonstrated in another work [18]. Improved bandwidth and isolation are achieved by combining stubs in the ground plane with a tapered feed line to create a compact quad-port Multiple-Input-Multiple-Output (MIMO) antenna [19].

This work focuses on the microstrip patch antenna design that includes design for both LTE and 5G MIMO antenna. LTE MIMO antenna with two elements and 5G MIMO system with four element antennas designed individually and then integrated on to the same substrate. This design also uses defective ground structure (DGS) approach to avoid higher coupling current effect. The suggested structure is created on a Rogers RO4350B substrate for its excellent frequency performance, low dielectric loss, good thermal conductivity, and high impedance stability. The paper is organized as follows. Section 2 describes design methodology. In Section 3, microstrip patch antenna design is discussed for both LTE, 5G MIMO antenna and their integration. Section 4 includes the simulated results and their comparison. Finally, conclusions are discussed in Section 5.

2 Methodology

A two-element MIMO structure is used in the design, and it is positioned on the board's top edge to support LTE frequency bands. MIMO antennas with four-elements are used in design, and they are framed on the board's extended edge to function at 5G mm-wave frequency bands. A parallel feed network and two elements make up each mm-wave MIMO antenna. The substrate used in the proposed design was Rogers RO4350B having a loss tangent of 0.0037. Substrate is 75 mm x 110 mm x 0.76 mm in size geometrically. Additionally, a method known as defective ground structure is utilized for improved isolation and radiation. The development is described firstly by LTE Design, 5G single-element antennas, MIMO structure, and lastly integration of both. The selection of an acceptable substrate is the first stage in antenna design.

The substrate is primarily necessary for providing the mechanical support to microstrip antenna. In order to offer this, the substrate should be of a dielectric; however, doing so can impair antenna's electrical functionality. Hence, a substrate simultaneously satisfying both criteria is challenging. A loss tangent of less than 0.005, which denotes a moderate amount of insertion loss, is required for the substrate material. In this investigation, we used RO4350B, which has a dielectric constant of 3.6. The glass fibre reinforced non-PTFE (non-polytetrafluoroethylene) hydrocarbon/ceramic laminates used in Rogers RO4350B, high-frequency materials are intended for high volume, high-performance commercial applications. The RO4350B laminates use the same production technique as traditional epoxy/glass, but they offer precise control over dielectric constant (Dk) and preserve low loss. It possesses the qualities needed by RF microwave developers and makes it possible to create filters, coupling networks, and impedance-controlled transmission lines in a repeatable manner. The Design specifications of proposed system are illustrated in Table 1.

Table 1. Design Specifications

Parameters	Value
Operating frequency	5.9GHz and 27.5GHz
Substrate dielectric material	Rogers RO4350B
Substrate dielectric constant	3.6
Substrate height	0.76mm

Continued on next page

Table 1 continued

Loss tangent	0.0037 dB/in
Feeding technique	Microstrip feedline
Impedance	50 Hms

3 Design of Microstrip Patch Antenna

A device's geometry must be accurate for it to function effectively. The following parameters are needed to construct a microstrip antenna using a standard procedure. The suggested design's frequency ranges are 5.6-6.5GHz and 26-30GHz. Therefore, 5.9GHz and 27.5GHz are the resonance frequencies used in this work. This design uses Rogers RO4350B, a dielectric material with a 3.6 dielectric constant. The conventional height of the dielectric substrate material for this design is selected as 0.76mm as it is the standard height of the Rogers RO4350B substrate. The key equations needed to carry out design of a rectangular patch antenna were developed. The rectangular patch design parameters were obtained using Equations (1), (2), (3), (4) and (5).

The patch width is obtained by:

$$Wp = \frac{c}{2f_o\sqrt{\frac{(\varepsilon_r+1)}{2}}} \tag{1}$$

Where c= speed of light

fo = resonant frequency

εr = effective permittivity

The effective constant of the Microstrip antenna is derived using;

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{\frac{1}{2}} \tag{2}$$

Where ε_r = Dielectric constant of substrate

ε_{reff} = Effective dielectric constant

h= dielectric substrate height

w = patch width

$$\triangle L = 0.412h\,\frac{(\varepsilon_{reff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{w}{h}+0.8\right)} \tag{3}$$

This extension of length ΔL expresses it as a function of the ratio $\frac{w}{h}$ and ε_{reff}.

The effective length for a given 'Lo' is:

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{reff}}} \tag{4}$$

Therefore the Actual length of the patch 'L' is:

$$L = L_{eff} - 2\triangle \tag{5}$$

CST Microwave Studio is used to model and simulate the proposed system. Determining the requirements for the microstrip patch antenna, such as the dielectric constant, substrate height, frequency operating, and loss tangent, etc., comes first in the implementation process. Then, measurements of the antenna's geometrical parameters, including patch width and length, are made. Following the basic Rogers substrate design, a rectangle patch and a microstrip feeding with a 50 ohm feed line were added. The replies were then produced by etching slots onto the ground plane. Therefore, all MIMO antennas were designed. Table 2 provides the 4G/LTE Antenna, 5G Antenna Array&4G/LTE and 5G Integrated Design Parameters of the proposed system respectively.

Table 2. 4G/LTE, 5G Antenna Parameters

4G/LTE		5G		Integrated Design	
Parameter	**Value(mm)**	**Parameter**	**Value(mm)**	**Parameter**	**Value(mm)**
LS	25mm	LS	6 mm	L	110 mm
Lf	8.76 mm	Lf	1.8 mm	W	75 mm
Lp1	3.4 mm	Sl	1.35 mm	H	0.76 mm
Wp2	3.3 mm	Lf1	4.4 mm		
Ws	21 mm	Lg1	12.5 mm		
Wf	2.2 mm	Ws	6.3 mm		
Wp1	3.4 mm	Wf	1.5 mm		
R1	6 mm	SW	2 mm		
Lp	11.82 mm	Wf1	1.6 mm		
Wp	19 mm	Wg1	1.32 mm		
Lp2	2.6 mm	Lp	4.2 mm		
Hp	0.75 mm	Wp	3.6 mm		
		Lf2	128 mm		
		Wf2	0.4 mm		
		R2	1.3 mm		

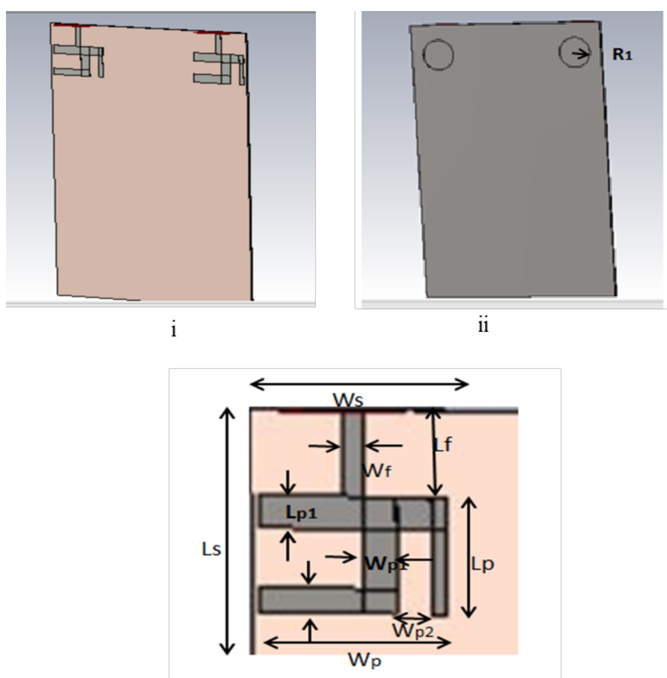

Fig 1. (i) Top and (ii) bottom view of LTE MIMO configuration (iii) Parameters of Y-shaped antenna

3.1 Design of LTE Antenna

An Inverted Y-shaped patch with microstrip feed line is designed after the parametric analysis, as depicted in the Figure 1**(i)**. Additionally, Figure 1**(ii)** shows bottom layer of the DGS loaded with a circular slot of radius R1 in order to change the ground current density, which enhances radiation performance and Figure 1 **(iii)** shows the design parameters of a two-element MIMO configuration with total length of 25mm out of 110mm and same substrate dimensions for width and height.

3.2 Design of 5G Millimeter-Wave antenna

The design was followed by a C-shaped patch with micro strip feed line as illustrated in Figure 2**(i)**. A radiating rectangular slot with the dimensions s1, sw is subtracted from the center of patch. After further development, the design becomes an array with two elements and corporate feed network. A parallel feed network with a T-junction structure connects the array's components. The array's two components are isolated by a distance of 2.4 mm, or around 0.25 at 27.5 GHz. Figure 2**(ii)** further shows that the antenna array's bottom ground is flawed with two circular and one rectangular slot and Figure 2 **(iii)** shows the design parameters.

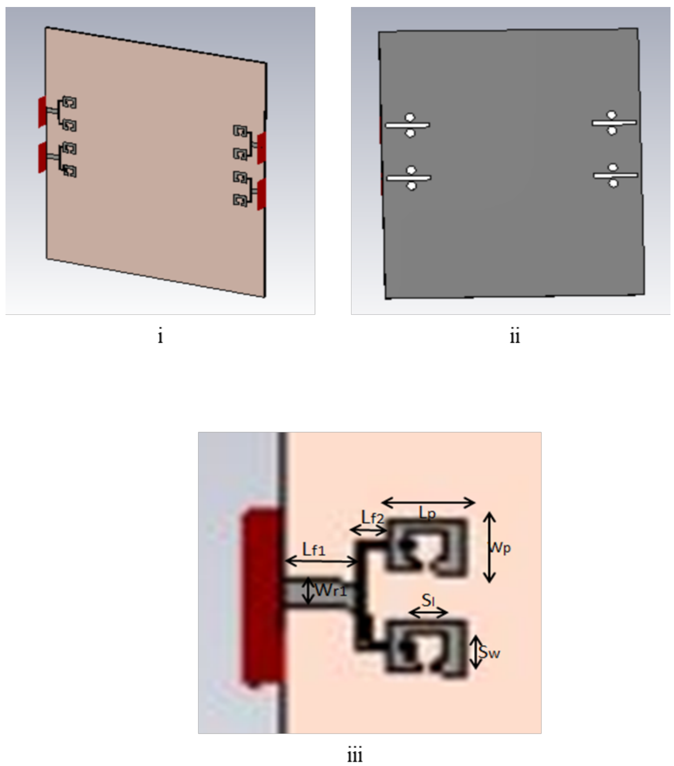

Fig 2. (i) Top (ii) bottom view (iii) and Parameters of antenna 5G MIMO configuration

3.3 Integrated design

Integrated Design is achieved by incorporating both 4G/ LTE and 5G MIMO antennas on the same substrate with size of LXWXH 75mm, 110mm, and 0.76mm. According to Figure 3**(i)**, the LTE module is mostly integrated at the substrate's top edge. The 5G MIMO antennas, in contrast, are positioned with their long edges facing one another. The final integrated proposed prototype's defective ground layer, which has rectangular and circular slots with optimal dimensions, is shown in Figure 3 **(ii)** combining LTE MIMO configuration and 5G millimeter Wave MIMO configuration on the same substrate. Wave guide port is then added to it.

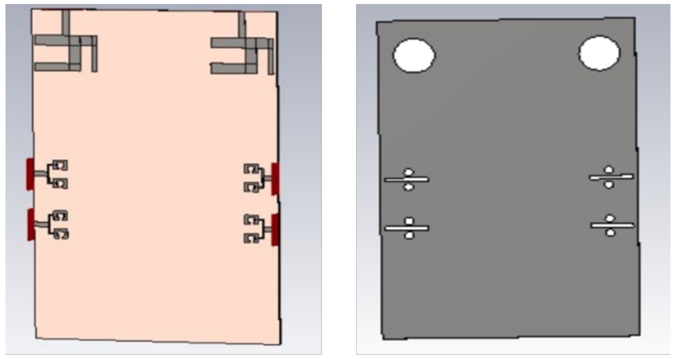

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Fig 3. (i) Top and (ii) bottom view of Integrated MIMO configuration

4 Result and Discussion

The simulated results using CST Microwave studio for S-parameters, Gain and Radiation pattern, Envelope correlation coefficient (ECC), diversity gain (DG) in CST microwave studio are discussed.

4.1 Antenna Performance Analysis: S-Parameters

Figure 4(**i**) shows the simulated reflection coefficient S1,1 & S2,2 of LTE Multiple Input Multiple Output antennas. The Antenna1 has resonated for the frequency range 6.35–6.46 GHz, while Antenna 2 now operates at the 6.33-6.43 GHz band. The obtained bandwidth for Antenna 1 was 110 MHz and Antenna 2 as 99 MHz. The simulated plot for transmission coefficients S2,1 & S1,2 curve is shown in Figure 4(**ii**). It shows an isolation of 33dB. The plot for reflection coefficient curves S3,3, S4,4, S5,5 & S6,6 for "mm-wave 5G MIMO" is shown in Figure 4(**iii**). Antenna 3 to Antenna 6 have resonated at frequency 27.5 GHz. The bandwidths observed are 2.7 for Antenna 3, 3.5 for Antenna 4, 4.5 Antenna 5 and 4.5 GHz for Antenna 6. From Figure 4 (**iv**), the isolation of 14 dB is observed between Antenna 3 and Antenna 5.

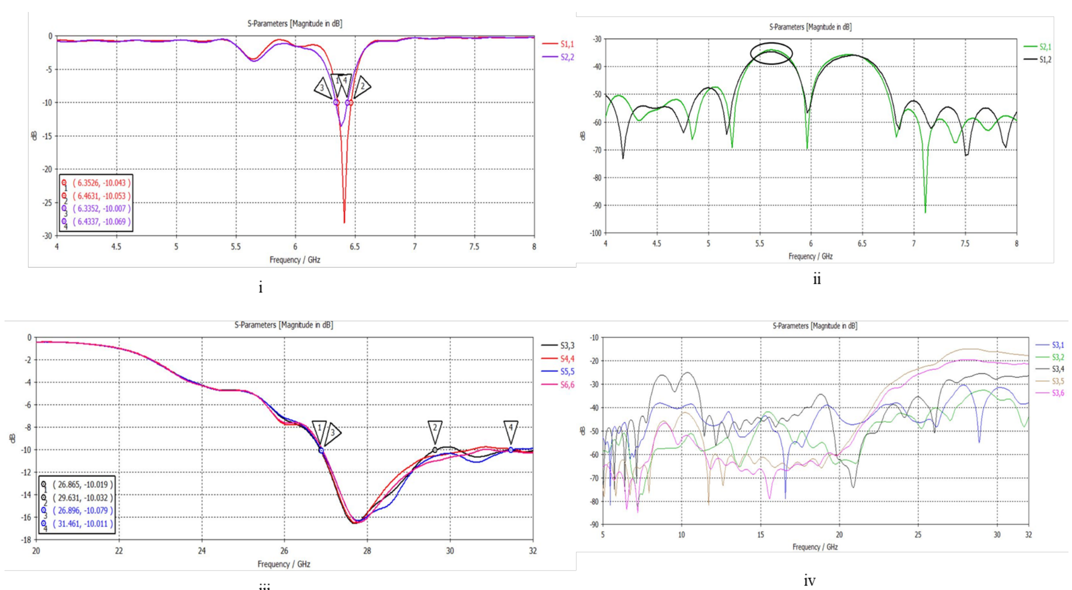

Fig 4. S-parameter curves for LTE MIMO Antennas (i) S1,1&S2,2- Reflection Coefficients (ii) S1,2 & S2,1-Transmission Coefficients (iii) Simulated Reflection Coefficient (iv) Transmission Coefficient for 5G MIMO Antennas Before and After Integration

Figure 5**(i-iv)** illustrates the results of the analysis of the observed surface current densities to support the functionality of the proposed MIMO structure. The investigation was done for LTE antennas at 5.9 GHz. At 27.5 GHz, the radiation and coupling effects of the current density of an MMW MIMO neighbouring elements were also investigated. The main current concentration for Ant1 was found to be along the lower strip of the LTE antenna as well as on the outer margins of the structure, and for Ant2, current density is broadly dispersed along the feedline and along the edges, as shown in Figure 5 **(i)**. Additionally, a little amount of current is seen around the ground plane's circular slots, which shows that the radiation behaviour may have been influenced by a defective ground structure. The same is investigated for antenna 3 at 27.5GHz, which is mostly c-shaped for mmw MIMO arrangement. It is noteworthy that all other 5G MIMO antennas have distributions that are quite comparable.

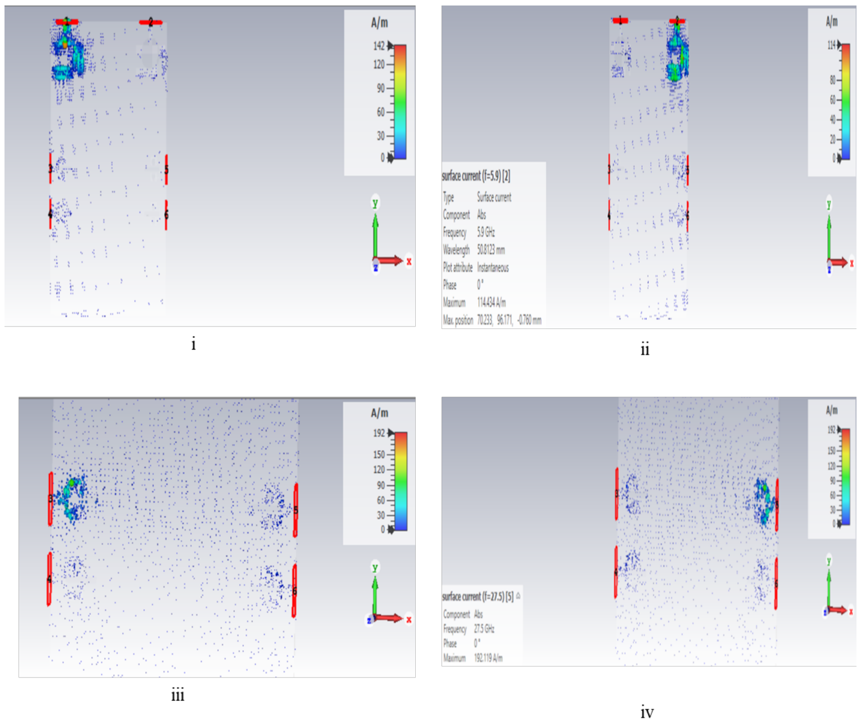

Fig 5. Surface Current Distribution for: (i) LTE Ant1; (ii) LTE Ant2 at 5.9GHz (iii) 5G Ant3; (iv) 5G Ant5 (For all 5G Antennas current distribution is investigated at 28 GHz)

4.2 Antenna Performance Analysis: Far-Field Results

Figure 6 **(i-iv)** displays the simulated 3D & 2D radiation patterns for Antenna 2 at 5.9 GHz and Antenna 5 at 27.5 GHz. Reduced field correlation required for MIMO operation, can be seen in the observation that the Ant1 maxima are slanted with respect to the Ant2 maxima.

4.3 MIMO Antenna Performance Analysis

Numerous important metrics, including ECC and DG, were examined to look into the performance of the suggested MIMO system design. ECC is a crucial performance metric for the MIMO antenna that shows how decoupled the MIMO elements are from one another. Diversity Gain (DG) is the amount of transmission power reduction without performance loss following the deployment of a diversity scheme for the MIMO antennas. Figure 7**(i-ii)** displays the correlation values for the developed LTE and 5G MIMO antennas. They were found to be much lower than the realistically reasonable Value of 0.5. Figure 7 **(iii-iv)** shows the diversity gain for the proposed integrated LTE system. It is noteworthy that the diversity gain for LTE antennas was around 9.99 dB, the diversity gain for 5G antennas was 10.02 dB for all-purpose antennas Ant3 and Ant5. As a result, the integrated antenna system that is being shown performs adequately in terms of diversity.

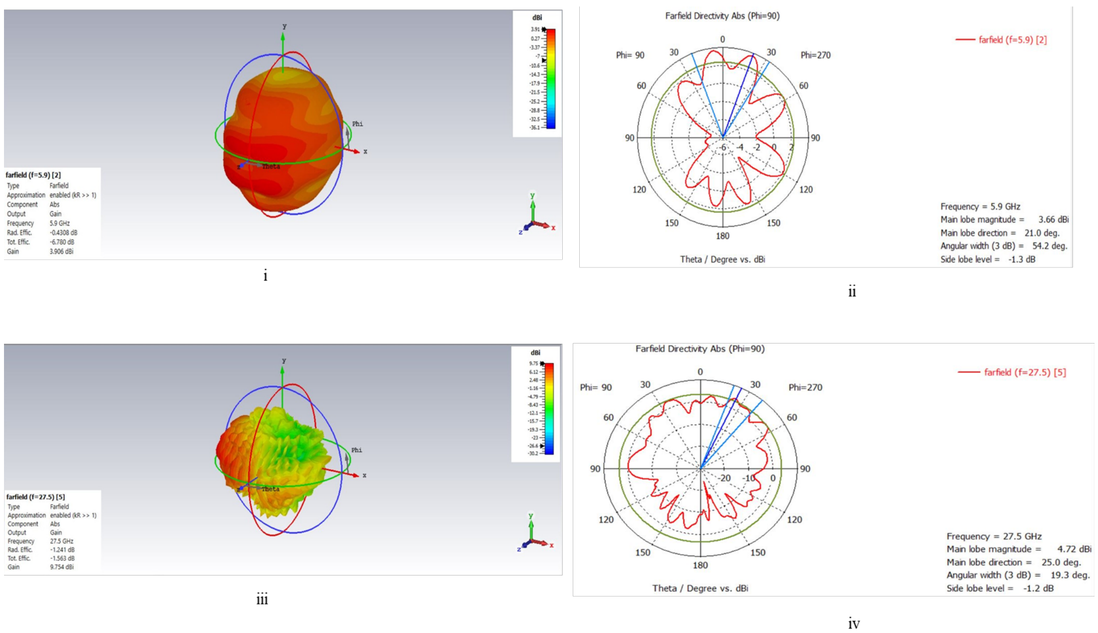

Fig 6. Simulated 3D Radiation patterns for (i) Ant1; (ii) Ant2; (iii) Ant 3; (iv) Ant 5, Simulated 2D Radiation patterns

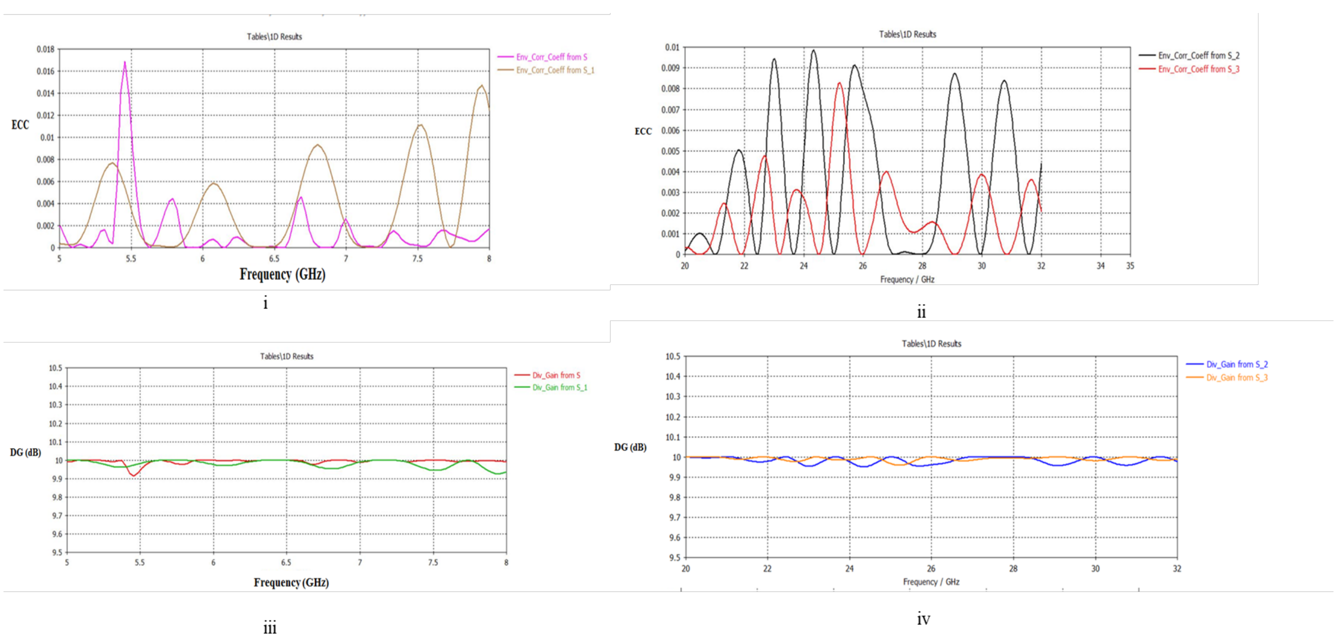

Fig 7. ECC for (i) LTE MIMO Antennas; (ii) 5G MIMO Antennas (iii) Diversity Gain for LTE MIMO Antennas; (iv) 5G MIMO Antennas

4.4 Comparison with Related Works

The proposed study is contrasted with related studies that have been published in the literature. Thus, it is clear that the proposed antenna has a minimal design complexity. Additionally, the achieved high gain and strong ECC make the proposed antenna system stand out in comparison to previous systems. This demonstrates that antenna design is appropriate for portable electronic gadgets in the future. Table 3 provides an overview of the results of the proposed system with few existing literature.

Table 3. Comparison of Proposed System Results with Literature

Ref.	size	Frequency	LTE		5G mmw	
			ECC	Gain (dB)	ECC	Gain (dB)
(9)	110 mm x75 mm x 0.508 mm	3.73-3.89, 5.40-5.85, 24.4-29.3 GHz	no	3.27,5.41	no	10.29
(17)	115 mm x 65 mm x 0.76 mm	1.9-3.2, 3.5-3.7, 25.7–30.5 GHz	no	5.1	no	9.9
(18)	100 mm x 60 mm x 0.76 mm	1.8-3.1 GHz, 27.2- 28.5 GHz	no	5	no	10
Proposed	110 mm x 75 mm x 0.76 mm	5.9 & 27.5 GHz	yes	Antenna 1at 4.1 & Antenna 2 at 3.9	yes	Antenna 3 at 9.9& Antenna 5 at 9.7

5 Conclusion

In this design, a combined 4G/LTE and 5G MIMO antenna system is shown in this work. While the 5G module has four MIMO components, the LTE system only has two MIMO elements. The LTE MIMO antenna module has a 110 and 99 MHz bandwidths and can operate between 5.6 and 6.5 GHz with a maximum of -10 dB. Similar to this, the mm-wave 5G MIMO antenna arrangement got a bandwidth of 2.7, 3.5, 4.5, and 4.5 GHz, which covered the 27.5 GHz band. Additionally, the design showed isolation of over 25 and 14 dB, respectively. Additionally, the suggested 5G MIMO and LTE antennas reached peak gains of 9.9 and 9.7 dB respectively at 27.5GHz, and 4.1 and 3.9 dB, respectively at 5.9GHz. Additionally, the investigation of the MIMO performance metrics reveals high field correlation performance across the operating bands as well as positive attributes. Therefore, the suggested design is a strong competitor for integrated communication devices due to aforementioned advantages.

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