



# Design of Parallely Window Slotted Multiband Miniaturized MIMO Antenna for Future Mobile Communications

G. Guru Prasad<sup>1</sup> · G. Senthil Kumar<sup>1</sup>

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## Abstract

A parallely window slotted MIMO Antenna using FR4 and silicon rubber as a substrate material is designed for future mobile communications is presented in this paper. The rectangular patch is modified with partial circular cuts along the radiating edges to ensure that the current takes a long-distance travel, so that gain is enhanced. Further slots are cuts toward the radiating edges, so that the amount of radiation from patch increases to increase the gain. The slot dimensions for patch were selected from 1/4th area of the rectangle, and using this measurement as radius, 1/4th portion of circular slots was made on top and bottom using clockwise and anti-clockwise directions. The novelty in this approach according to field theory is selecting the dimension and shape of slot on patch at opposite corners. Hence, 1/4th part of patch area can be removed, so that patch antenna will be miniaturized. Performance evaluations were done and compared for both single antenna and MIMO antenna with and without window slots using FR4 and silicon rubber substrates. This antenna covers six bands in 5G NR bands (new radio) like N7 (2.5–2.57 GHz), N8 (2.57–2.62 GHz), N41 (2.496–2.69 GHz), N53 (2.483–2.495 GHz), N79 (4.4–5.0 GHz), and N90 (2.496–2.690 GHz) apart from Bluetooth and WLAN. Proposed antenna can be used in future mobile phones with hexa-band operation.

**Keywords** Window slotted · FR4 and rubber substrate · Multiband · Miniaturized · MIMO antenna · Future mobile communication

## Introduction

In the future mobile communications, the entire world will be changing with modern antenna design for cell phones and base stations (BSC) with better transmission data rate, sharper latency, and improved access speed, that have definite improvements over existing 4G system. The application of 5G smart phone communication comes from several areas like IoT, Virtual Reality, and cloud-powered applications.

Subsequently, the requirement for higher data rates with enhanced reliability in the mobile phone also appeared as crucial requirement. These challenges include higher value in video calls, streaming HD videos, and play quality online games. Similarly, COVID pandemic underlined the consequence of high throughput in network connections required for remote working [1]. For beyond 5G communications or future communications, the MIMO operation with greater than two air data traffic streams arrives to greatly improve the traffic data throughput. To deal with recent development trend, engagement of additional compact or high-order MIMO antennas required for the service access terminals and mobiles have become one of the most key tasks. Especially, due to limited space in mobiles, compact MIMO antennas are needed to be developed [2].

A 10-element MIMO antenna is designed functioning in sub 6 GHz frequency band. Proposed slotted antenna is fed with the T-shape line feeding, hence called as double T. Antenna is designed for 42, 43, and 46 bands of LTE. This design has more channel capacity with size  $1 \times 8$  cm. Here, antenna size is reduced as well as improves in number

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✉ G. Guru Prasad  
guru.p6@gmail.com  
G. Senthil Kumar  
gskkanchi@gmail.com

<sup>1</sup> Department of Electronics and Communication Engineering, Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya, Kanchipuram, India

of operating bands [3]. A broadband MIMO antenna with PIFA is designed for a 5G smart phone operating at N77, N79, N78, and LTE 46 band. Inverted T-shaped open slot was made to improve the band width. Size of antenna is  $15 \times 7.5$  cm without a clear ground [4]. Three types of radiating patches were made on a common ground to achieve bands in sub 6 bands of 5G. Inverted L molded open slot was made on sub 6 GHz radiator to improve the bandwidth and also high isolation between the bands were achieved [5]. Eight-element antenna is used for achieving 3 bands of 5G communications. It consists of two identical subarray pairs of antennas on common ground. Dimensions of the substrate are that of a standard smart phone size, i.e.,  $150 \text{ mm} \times 75 \text{ mm} \times 0.8 \text{ mm}$ . system ground plate is placed on back side of the substrate with a dimension of  $14 \text{ cm} \times 7.5 \text{ cm}$ . To accommodate two LTE/Wireless WAN antennas for 2, 3, and 4G bands of operation, two rectangular-shaped ground plate allowance portions of  $75 \text{ mm} \times 5 \text{ mm}$  at both the upper and bottom edge of the baseplate were reserved [6].

Review on massive MIMO antennas was presented among them. An UWB slot loaded antenna is designed to operate at C, V, and W bands that cover Wi-Fi and WiMAX bands. To achieve notching between frequency bands, two types of ground plates are used: one type is normal ground and other one is mushroom grounded (ground plate consisting of array of patches). The separation between elements was adjusted to achieve better notch and pass bands [7]. Hexagonal-shaped patch antenna is designed to function at resonant frequency. Later, certain modifications in patch geometry was modified to get further resonant frequencies. Modifications in patch geometry are done in terms of adding inductive and capacitive-loaded parts to hexagonal patch. This newly modified patch exhibited four new frequencies with better return loss, gain, and efficiency suitable for future mobile handsets [8]. Two sets of MIMO antenna of  $4 \times 4$  size is designed on common ground one pair operating for 4G and other pair operating for 5G bands. The designed antenna does not require any additional switching elements, so that antenna is free from ohmic losses; further space is present in antenna for adding additional elements [9].

Eight-element MIMO antenna is designed using monopoles. LC-loaded stubs were inserted to ground plane to reject unwanted bands and improve isolation. The designed antenna can be used for 3G, 4G, and 5G UWB applications. Orthogonal placement of four monopoles improves the polarization diversity of antenna [10]. Eight inverted L-shaped antennas were placed on a common ground to achieve  $8 \times 8$  MIMO antenna. Four stubs were used to achieve the desired bands. Designed antenna operated at (3.3–3.7) GHz bands. Different S parameter plots were plotted by adjusting the height of the substrate [11]. Eight folded monopoles were inserted on a fully grounded

plane were two pairs of monopoles which were placed in an orthogonal manner. Designed MIMO antenna operated at (3.10–3.85) GHz of sub 6 GHz band [12]. A two-component Pharaonic Ankh Key type antenna is designed, operating at 24 GHz, 28 GHz, 37 GHz, 39 GHz, and 47 GHz bands covering 5G bands [13]. Three port equilateral triangle patch antenna is designed using three capacitive-loaded L-shaped strips at three edges of ET. Designed antenna is operated at N77 band of 5G [14].

Wide-band MIMO antenna of eight elements were designed with inverted F shape and inverted L- and C-shaped shorting elements were used for proper matching purpose. Designed antenna covers N77, N78, and N79 bands of 5G [15]. T- and E-shaped slots were made on metal frame of smartphone for generating (3.3–6) GHz 5G band. Modified H-shaped slots were made between the slots for getting better isolation [16]. An EBG structured ground is used and two E-shaped patches were made on two sides of ground to operate antenna at (2.65–2.95) GHz frequency bands of 5G mobile communication of a mobile phone [17]. A Frequency Selected Structure (FSS)-Based MIMO Antenna is designed for applications of WLAN, 5G Cellular, WiMAX, and Wi-Fi. T- and E-shaped gaps were made on the FSS of patch. Advantage is MIMO operation. Disadvantage is poor isolation [18]. Aperture-paired cylindrical-shaped dielectric resonator antenna is designed for GPS, Wi-Fi, and WiMAX bands of a smart phone [19]. Quad antenna system is designed with two pair of antennas. One pair of antennas is for one type and other pair is of other kind on metal frame without any decoupling structure. Designed antenna covered GPS, 4G, and 5G bands [20]. However, designing individuals MIMO antennas has their own pros and cons. Hence, combining these issues progresses in designing the proposed antenna. Design methodology implemented in this paper is innovative and simple according to field theory. Proposed antenna covers six 5G bands with more than 7 dBi gain. In this research paper, two-component MIMO antenna is introduced for future mobile communications of a smartphone functioning within the  $-7$  dB return loss. The proposed antennas are evaluated using FR4 and rubber substrates. The proposed antenna shall be useful in 5G mobiles with hexa-band operation.

## Design of Parallely Window Slotted Multiband Miniaturized 2-Element MIMO Antenna

Here, the rectangular patch is modified with partial circular cuts along the radiating edges to ensure that the current takes a long-distance travel, so that gain is enhanced. Further slots are cuts toward the radiating edges, so that the amount of radiation from patch increases to increase the gain. The two

approaches with FR4 and rubber substrates were developed and analyzed using transmission line model. Dimensions of rectangular-shaped patch antenna are calculated by transmission line model and antenna is designed at 2.4 GHz resonant frequency; substrate height ( $h$ ) is deemed as 1.6 mm and substrate type is selected as FR4 and rubber

$$f_r = 2.4\text{GHz} \tag{1}$$

$$h = 1.6\text{mm} \tag{2}$$

$$\epsilon_r = 4.4(\text{FR4}). \tag{3}$$

Patch shape considered: rectangle.

Patch width is calculated by

$$W = \frac{C}{2f_r} \sqrt{\frac{2}{\epsilon_r + 1}} = 0.038\text{m} = 38\text{mm}. \tag{4}$$

Effective length is calculated by

$$L_{\text{eff}} = \frac{C}{2f_r \sqrt{\epsilon_{\text{reff}}}} = \frac{0.0625}{2.08} = 30\text{mm}. \tag{5}$$

Length to compensate the fringing field is

$$\begin{aligned} \Delta L &= h \times 0.412 \times \frac{(\epsilon_{\text{reff}} + 0.3) \left(\frac{W}{h} + 0.264\right)}{(\epsilon_{\text{reff}} - 0.258) \left(\frac{W}{h} + 0.8\right)} \\ &= 0.6592 \times (4.63 \times 24.014) / (4.072 \times 24.55) = 0.733. \end{aligned} \tag{6}$$

Length of the patch is calculated by

$$L = L_{\text{eff}} - (2 \times \Delta L) = 30 - 1.466 = 28.54\text{mm} \tag{7}$$

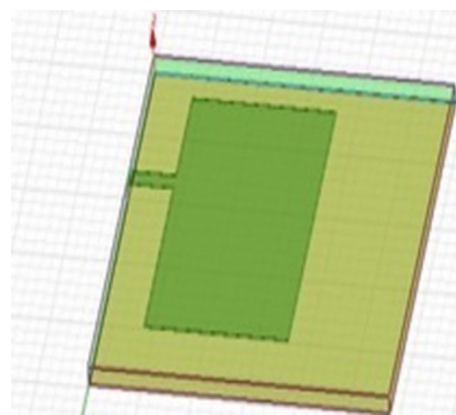
$$\text{Ground plate length } L_g = 6h + L = 38.14\text{mm} \tag{8}$$

$$\text{Ground plate width } W_g = 6h + W = 47.6\text{mm}. \tag{9}$$

Similarly, dimensions of antenna for rubber substrate were calculated and are tabulated in Table 1. The designs are

**Table 1** Antenna design parameters for FR4 substrate and rubber substrate

Parameters	RPA with FR4 substrate (mm)	RPA with rubber substrate (mm)
Width of the patch	38	31
Effective dielectric constant	4.33	5.46
Length of the patch	28.54	21.70
Length of ground plate	38.14	31.3
Width of ground plate	47.6	40.6



**Fig. 1** Designed rectangular patch antenna

simulated using Ansys HFSS Tool to assess various parameters like S parameter, VSWR, antenna gain, and radiation pattern.

Here, a patch antenna is designed at 2.4 GHz frequency; semi-circular slots made for rectangular patch and parallelly window slots made to semi-circular patch using HFSS simulation software.

The slot dimensions for patch were selected from 1/4th area of the rectangle, and using this measurement as radius, 1/4th portion of circular slots was made on top and bottom using clockwise and anti-clockwise directions. The novelty in this approach according to field theory is selecting the dimension and shape of slot on patch at opposite corners. Hence, 1/4th part of patch area can be removed, so that patch antenna will be miniaturized. Designed patch antenna using strip feed is shown in Fig. 1. Designed Antenna with circular corner cuts is shown in Fig. 2. Two inductively loaded window slots were made on a partially circular cutted patch. The modified patch is shown in Fig. 3. Designed two-element MIMO antenna with circular corner cuts shown in Fig. 4. Designed two-element parallelly window slotted MIMO antenna shown in Fig. 5.

Patch antenna with partial circular cuts and  $2 \times 1$  MIMO is designed with FR4 substrate. Parallelly window slotted antenna and  $2 \times 1$  MIMO parallelly window slotted antenna are designed using FR4 and silicon rubber as substrate material. Innovatively, dimensions and geometry of patch and slots were selected. All antennas were fed with inverted I-shaped micro-strip feedline and linked to ground plate using SMA connector. Boundary restrictions state that divergent part of electric field will be zero on a perfect conductor and the electric field component disappears at edges of the slots. Distance between two patch elements is made at least  $\lambda/2$  to reduce mutual coupling effect. From Fig. 3, it was observed that two patch elements were made with partial circular cuts and embedded with two parallel window slots in each patch. Slot dimensions were selected

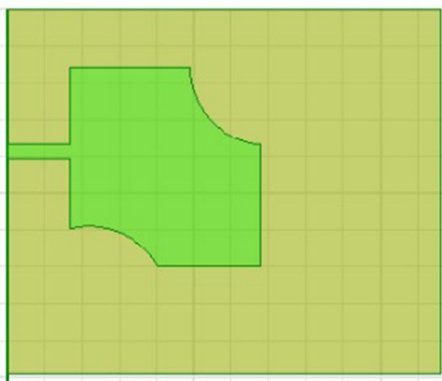


Fig. 2 Designed rectangular patch antenna with partial circular cuts

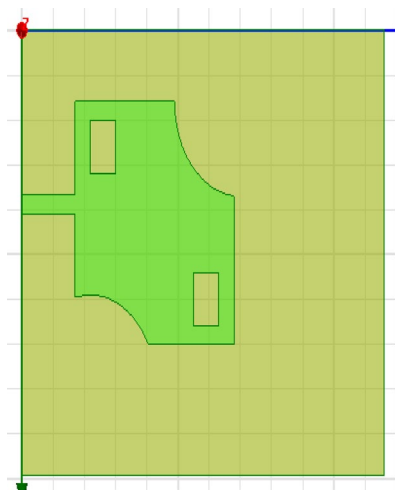


Fig. 3 Designed parallelly window slotted patch antenna

as 2.5 mm × 3.1 mm. A few things were observed by loading slots on patch and explained below.

### Role of Window Slots on Patch

Reactive load is caused due to coupling between two window slots on patch which mainly depends on geometry of patch and dimensions of window in terms of length and width. Several combinations of length and width of window slot were simulated in trial-and-error basis to operate antenna in required bands of frequency. Further other dimensions of partial circular cuts on opposite edges of patch are varied depending on window diagonal length, considered as radius of partial circular cuts is varied from minimum to maximum value to enhance the antenna performance at multiband frequencies. The first operating frequency band is obtained due to the rectangular patch designed at resonant



Fig. 4 Designed 2 × 1 MIMO antenna with partial circular cuts

frequency. The second frequency band is obtained by partial circular cut on top right corner of patch. Third frequency is generated due to partial circular cuts at bottom left of patch. Fourth and fifth frequency bands were obtained because of two window slots placed on opposite directions of patch.

### Loading Patch with Inductively Coupled Structures

Two inductively loaded window slots were made on a partially circular cutted patch. The modified patch is shown in Fig. 3. From simulated s parameter plot, it is observed that antenna operated at five frequency bands. The imaginary part of input impedance is vanished to zero and real part is closer to 50 Ω. Hence, the slotted antenna is considered to be a good impedance matched antenna at all the five operating bands. It was observed that magnitude of reflection coefficient is very less at these operating frequency bands.

### Loading Capacitively Coupled Elements to Patch

For better improvement of antenna parameters, main patch is loaded with two open slotted windows. One window acts as positively charged plate and other window acted as negatively charged plate to induce capacitive effect on patch. The geometrical shape, position, and dimensions of window control the functioning of antenna at multiple frequency bands. The reactive coupling between two windows depends on gap between windows as well as dimension, shape, and position of window.

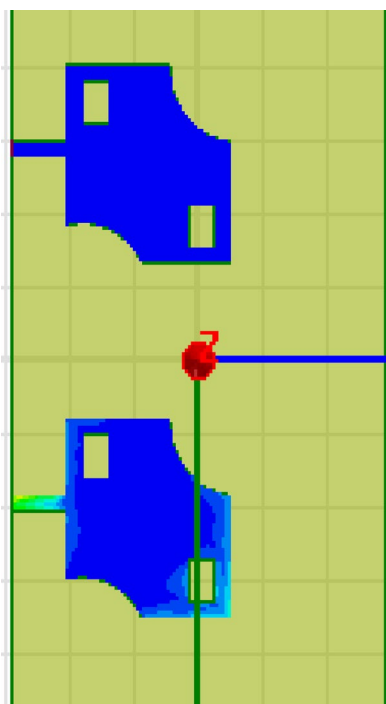


Fig. 5 Designed parallelly window slotted 2 × 1 MIMO antenna

### Analysis of Simulated Results

Patch antenna with partial circular cuts using FR4 substrate, 2 × 1 MIMO patch antenna with partial circular cuts using FR4 substrate, parallelly window slotted antenna, and parallelly window slotted with MIMO type antenna using Fr4 and silicon rubber substrates is designed and simulated in the range of 1–10 GHz using HFSS. Different antenna parameters involving reflection coefficient, VSWR, radiation patterns, and gain were noted and plotted.

### Simulated Results for Parallelly Window Slotted Antenna

*Return loss* Simulated *S* parameter for parallelly window slotted antenna is presented in Fig. 6. It was noted that designed antenna functioned at five frequency bands, i.e., (2.4–2.6) GHz, (3.2–3.4) GHz, (4.6–5) GHz, (6.8–8.2) GHz, and (9.4–10) GHz.

### Effect of Slots on S-Parameter of Antenna

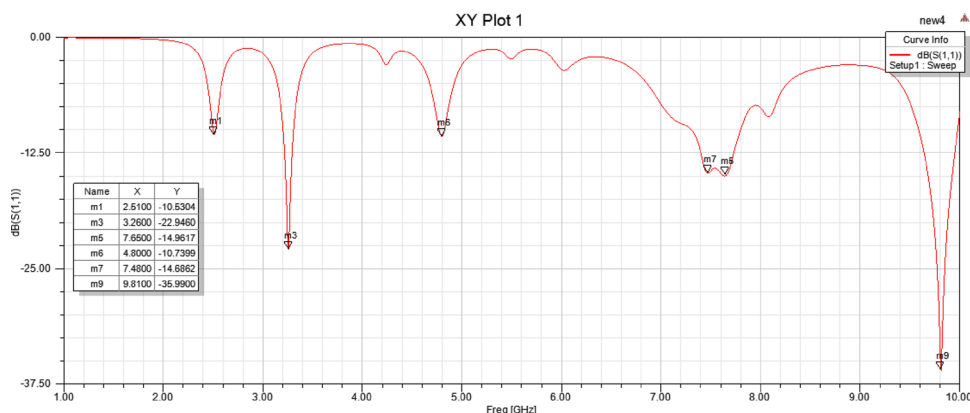
Several combinations of length and width of window slot were simulated in trial-and-error basis to operate antenna in required bands of frequency. Further other dimensions of partial circular cuts on opposite edges of patch are varied depending on window diagonal length, considered as radius of partial circular cuts is varied from minimum to maximum value to enhance the antenna performance at multiband frequencies. The first operating frequency band is obtained due to the rectangular patch designed at resonant frequency. The second frequency band is obtained by partial circular cut on top right corner of patch. Third frequency is generated due to partial circular cuts at bottom left of patch. Fourth and fifth frequency bands were obtained because of two window slots placed on opposite directions of patch.

*VSWR* VSWR plot of parallelly window slotted antenna is shown in Fig. 7. At 2.45 GHz band, attained VSWR is around 2.1, at 3.3 GHz band, attained VSWR is around 1.97, at 4.8 GHz band, attained VSWR is around 1.6, at 7.40 GHz band, attained VSWR is around 1.6, at 8.2 GHz band, attained VSWR is around 1.5 and at 9.80 GHz band, and attained VSWR is around 1.4.

*Radiation Patterns* 2D radiation patterns of parallelly window slotted patch antenna are indicated in Fig. 8.

Gain of patch antenna with partial circular cuts using FR4 substrate is shown in Fig. 9. From the gain plot, it is noted that gain of parallelly window slotted antenna is 1.13 dBi.

Fig. 6 Simulated *S* parameter plot for parallelly window slotted patch antenna



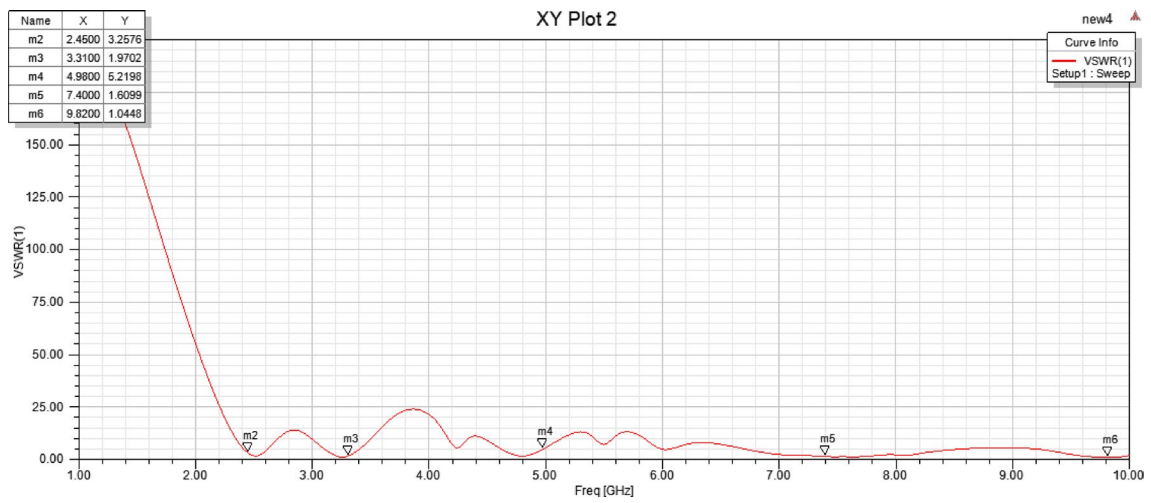


Fig. 7 VSWR plot for parallelly window slotted antenna

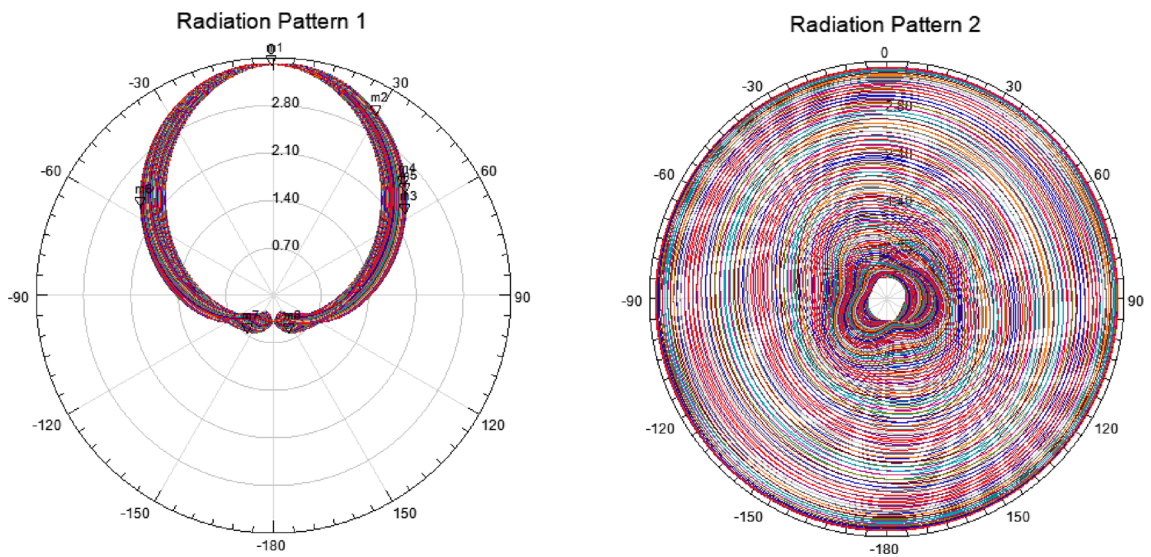
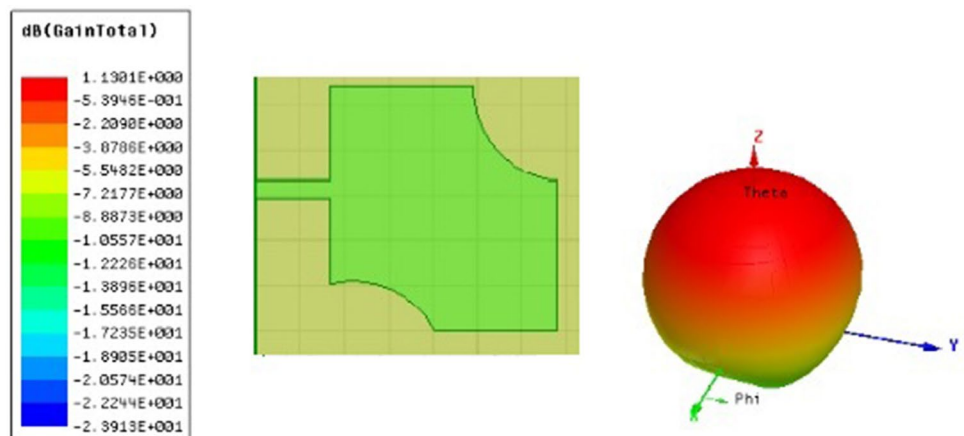
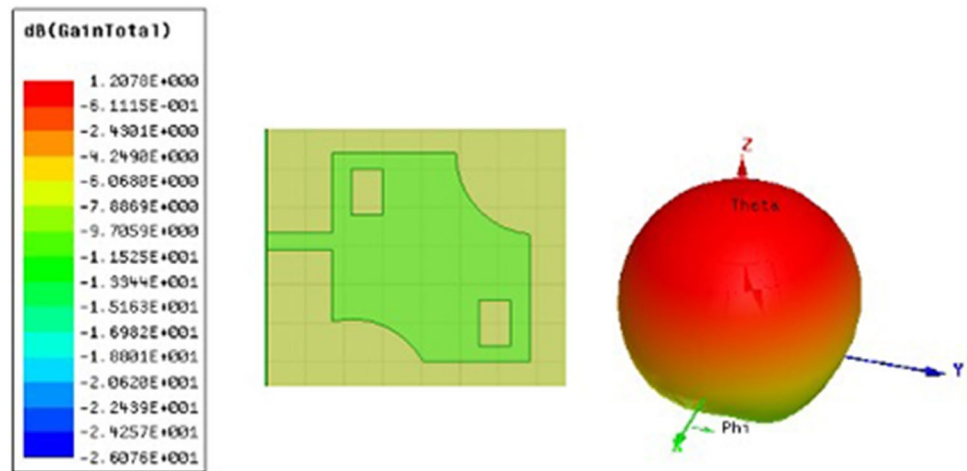


Fig. 8 2D radiation patterns of parallelly window slotted antenna

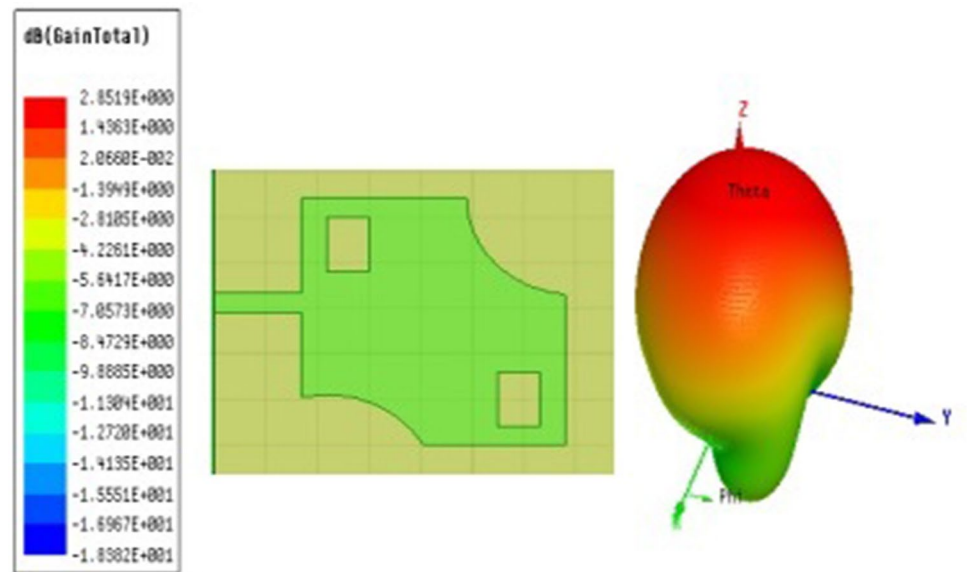
Fig. 9 Simulated gain for slotted patch antenna with partial circular cuts



**Fig. 10** Simulated gain for parallelly window slotted patch antenna employing FR4 substrate



**Fig. 11** Gain plot for parallelly window slotted antenna employing silicon rubber substrate



Gain of parallelly window slotted patch antenna using FR4 substrate is shown in Fig. 10. From the gain plot, it is noted that gain of parallelly window slotted antenna is 1.20 dBi.

Gain of parallelly window slotted patch antenna using silicon rubber substrate is plotted in Fig. 11. Gain of antenna is noted as 2.85 dBi.

Simulated 2D radiation plots for parallelly window slotted antenna using silicon rubber substrate are shown in Fig. 12.

Gain of parallelly window slotted MIMO antenna using FR4 substrate is presented in Fig. 13. Gain of slotted antenna is noted about 6.57 dBi.

Simulated 2D radiation plots for parallelly window slotted MIMO antenna using silicon rubber substrate are shown in Fig. 14.

Gain of parallelly window slotted MIMO antenna using FR4 substrate is shown in Fig. 15. From the graph, gain of antenna is about 7.07 dBi.

Gain of parallelly window slotted MIMO antenna using rubber substrate is shown in Fig. 16. From the graph, gain of antenna is about 7.29 dBi.

Designed MIMO antenna results for both FR4 and rubber substrates with and without window slots were analyzed. Results of MIMO antenna justified with good qualities of operating frequency bands and gain compared with the other designs. Summary of simulated results for two types of antennas, i.e., antenna with partial circular cuts and MIMO antenna with partial circular cuts, is tabulated in Table 2. Summary of simulated results for parallelly window slotted antenna using two types of substrates FR4 and rubber is tabulated in Table 3. From Table 3, it was practical that

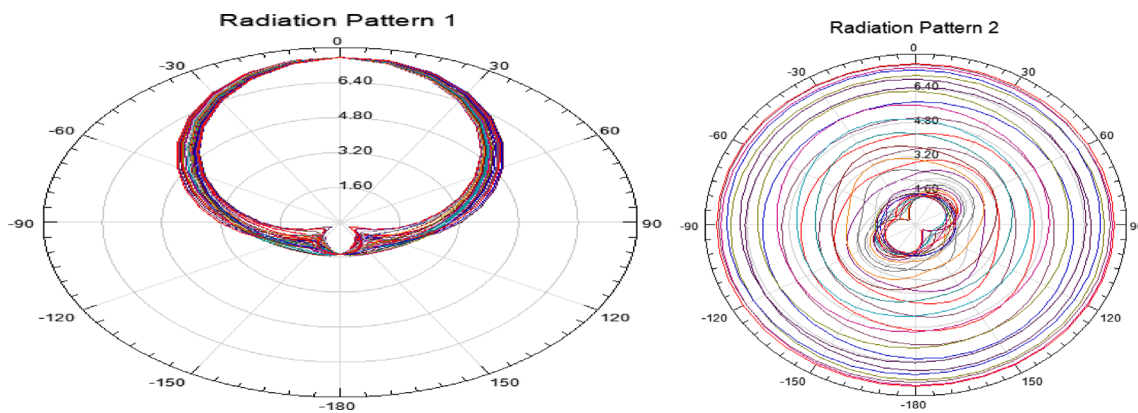


Fig. 12 Simulated 2D radiation pattern for parallel window slotted antenna employing silicon rubber substrate

Fig. 13 Simulated 3D radiation pattern slotted MIMO antenna with partial circular cuts

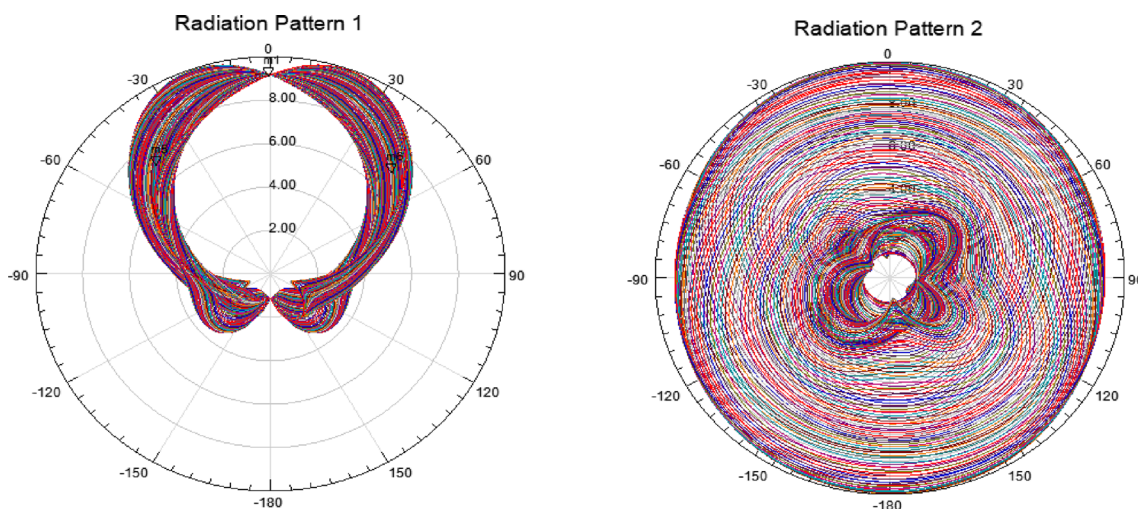
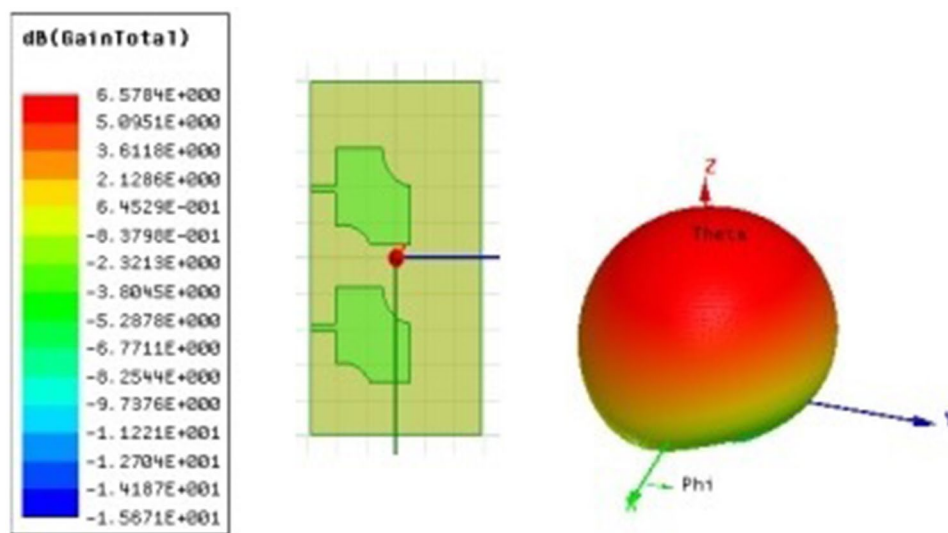


Fig. 14 Simulated 2D radiation pattern for parallel window slotted 2x1 MIMO antenna using rubber substrate



antenna was operated at almost similar bands for all the designs and gain was improved from 1.20 to 7.29 dBi. For parallelly window slotted antenna gain improved from 1.20 to 2.85 dBi using FR4, rubber substrates. Similarly, for parallelly window slotted 2×1 MIMO antenna, gain improved from 6.57 to 7.29 dBi using FR4 and rubber substrate. Gain improved from 1.20 to 6.57 dBi using FR4 substrate of the parallelly window slotted antenna and 2×1 MIMO antenna. Similarly, gain improved from 2.85 to 7.29 dBi using rubber substrate of the parallelly window slotted antenna and 2×1 MIMO antenna. Gain comparison of patch antenna with partial circular cuts: with and without parallel window slotting techniques for single antenna and MIMO is tabulated in Table 4.

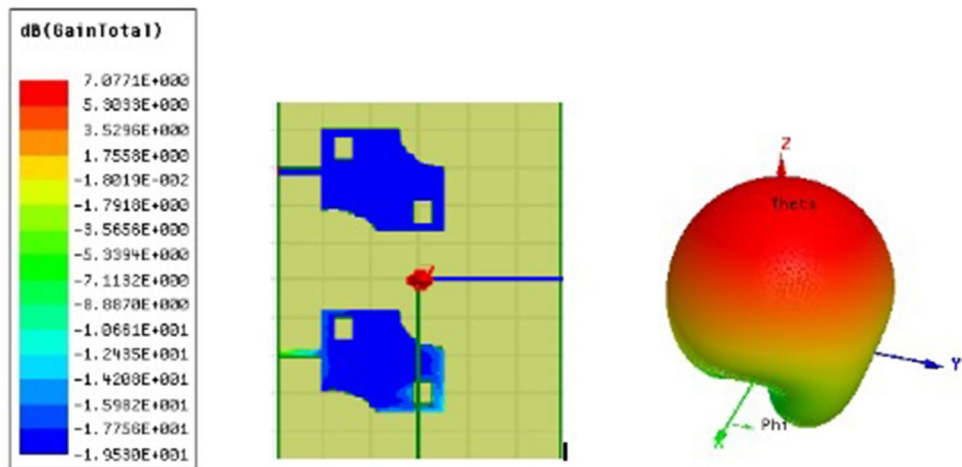
Summary of results of antenna with partial circular cuts using FR4 substrate and 2×1 MIMO antenna with partial circular cuts using FR4 substrate is presented in Table 2.

It was observed that single antenna and 2-element MIMO antenna were operated at almost same frequency bands, but gain of the antenna is improved from 1.13 to 6.57 dBi.

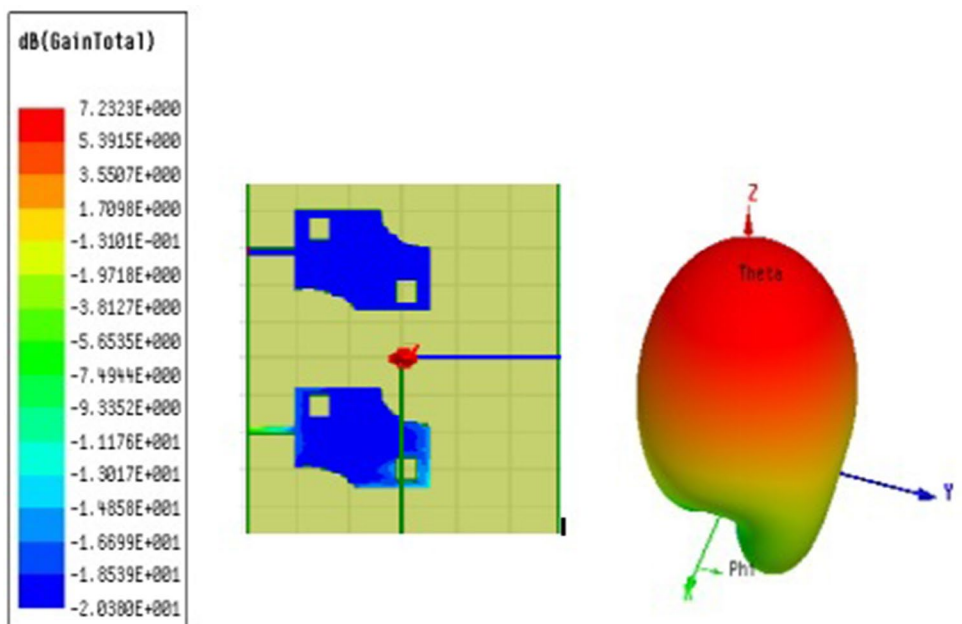
Summary of simulated results of parallelly window slotted Antenna and parallelly window slotted MIMO antenna using FR4 and rubber substrates is presented in Table 3. It was observed that single antenna and 2-element MIMO antenna were operated at almost same frequency bands, but gain of the antenna is improved. For parallelly window slotted antenna, gain of the antenna is improved from 1.20 to 2.85 dBi for FR4 to rubber substrates and for parallelly window slotted MIMO antenna gain of the antenna is improved from 7.07 to 7.29 dBi for FR4 to silicon rubber substrates.

Summary of simulated results of antenna with partial circular cuts, parallelly window slotted antenna, 2-element MIMO antenna with partial circular cuts, and parallelly window slotted 2-element MIMO antenna using FR4 substrate is

**Fig. 15** Simulated 3D radiation pattern for parallelly window slotted 2×1 antenna using FR4 substrate



**Fig. 16** Simulated 3D radiation pattern for parallelly window slotted 2×1 antenna using rubber substrate



**Table 2** Comparison of antenna parameters for antenna with partial circular cuts with and without MIMO using FR4 substrate

Antenna type	Substrate	Return loss (GHz)	Gain (dBi)
Antenna with partial circular cuts	FR4	2.4–2.6, 3.2–3.6, 4.8–5.2, 7.2–8.8, 8.2–8.4, 9.6–10	1.13
2 × 1 MIMO antenna with partial circular cuts	FR4	2.4–3.1, 3.8–4.1, 5.8–6.2, 7.2–7.4, 8.4–10	6.57

**Table 3** Comparison of antenna parameters for parallelly window slotted antenna using FR4 and rubber substrates

Antenna type	Substrate	Operating frequency bands (GHz)	Gain (dBi)
Parallelly window slotted antenna	FR4	2.4–2.6, 3.2–3.4, 4.6–5.0, 6.8–8.2, 9.4–10	1.20
	Rubber	2.4–2.6, 3.1–3.5, 4.4–5.9, 7.0–8.8, 9.4–10	2.85
Parallelly window slotted MIMO antenna	FR4	2.4–2.6, 3.1–3.3, 4.6–5.8, 5.8–6.1, 9.2–10	7.07
	Rubber	2.4–3.1, 3.7–3.9, 4.8–5.1, 7.2–7.4, 8.4–10	7.29

presented in Table 4. It was observed that all types of antennas were operated at almost same frequency bands, but gain of the antenna is improved from 1.13 to 7.07 dBi.

Simulated results of proposed antenna were compared with the existing designs implemented in references [1, 3, 8, 9, 11, 12] in terms of feeding techniques, operating frequency bands, number of frequency bands, and gain of the antennas which are tabulated in Table 5.

From Table 5, it was observed that all designs were implemented using micro-strip line feeding technique for

different shapes of antennas. The design implemented in [1] operated at only two bands for unlicensed frequency bands used for WIFI and WiMAX communications with antenna gain of 5.8 dBi. A 10-element MIMO antenna is designed in [3] functioning in sub 6 GHz frequency band. The proposed T slotted antenna is fed with the T-shaped strip line is designed to operate for three frequency bands in LTE including LTE band 42, LTE band 43, and LTE band 46 with gain of 6 dBi. Hexagonal-shaped patch antenna implemented in [8] is modified in patch geometry to resonant frequencies at four frequency bands with gain of 7 dBi. Two sets of MIMO antenna of 4 × 4 size are designed on common ground in [9]: one pair operating for 4G and other pair operating for 5G bands. Total obtained bands are 3 with gain of 5 dBi. Eight inverted L-shaped antennas were placed on a common ground to achieve 8 × 8 MIMO antenna in [11]. Designed antenna operated at (3.3–3.7) GHz, bands with antenna gain of 4 dBi. Eight folded monopoles were inserted on a fully grounded plane were two pairs of monopoles were placed in an orthogonal manner in [12]. Designed MIMO antenna

**Table 4** Gain comparison of patch antenna with partial circular cuts: with and without parallel window slotting techniques for single antenna and MIMO

Antenna type	Substrate	Gain (dBi)
Antenna with partial circular cuts	FR4	1.13
Parallelly window slotted antenna	FR4	1.20
2 × 1 MIMO antenna with partial circular cuts	FR4	6.57
Parallelly window slotted MIMO antenna	FR4	7.07

**Table 5** Parameters’ comparison of proposed antenna with other existing antennas

Antenna design	Feeding technique	Operating frequency bands (GHz)	No. of frequency bands	Antenna gain (dBi)
[1] Circular patch Antenna with 3 linear slots	Microstrip line	6.425–7.125, 5.925–7.125	2	5.8
[3] T-shaped slot antenna	Microstrip line	3.40–3.60, 3.61–3.8, 5.15–5.925	3	6
[8] Hexagonal patch antenna	Microstrip line	27.7–28.3, 42.70–43.3, 51.20–53, 55.7–57.5	4	7
[9] Γ-shape strip antenna	Microstrip line	3.3–3.8, 4.8–5.0, 5.150–5.925	3	5
[11] Inverted L-shaped antenna	Microstrip line	3.3–3.7	1	4
[12] Folded monopole antenna	Microstrip line	3.10–3.85, 4.8–6.0	2	6.23
Proposed antenna	Microstrip line	2.4–2.6, 3.2–3.6, 4.8–5.2, 7.2–7.8, 8.2–8.4, 9.6–10	6	7.29

operated at 3.10–3.85 GHz, 4.8–6.0 GHz in 2 bands of sub 6 GHz band with antenna gain of 6.23 dBi. From the summary of proposed design to existing designs in Table 3, the proposed work is better in terms of achieving six 5G bands with more than 7 dBi gain compared with the existing approaches present in literature summarized in Table 3. It was assured that the proposed design will be useful MIMO system for the future mobiles operating with 6 N frequency bands of 5G.

## Conclusion

A parallelly window slotted MIMO antenna is designed using Fr4 and silicon rubber substrates for future mobile communications. Designed antenna is functioned at hexa-band frequency of partial 5G NR bands (new radio) like N7 (2.5–2.57 GHz), N8 (2.57–2.62 GHz), N38 (5.57–2.62 GHz), N41 (2.496–2.69 GHz), N79 (4.4–5.0 GHz), and N90 (2.496–2.690 GHz) apart from Bluetooth and WLAN. HFSS simulator is used for antenna design and simulation. By incorporating the novelty technique in selecting patch shape with partial circular cuts and two parallel window slots on patch, the proposed antenna dimensions have been miniaturized around 50% and improve gain to 7.50 dBi. Antenna parameters involving return loss, VSWR, gain and radiation patterns of single antenna and 2 × 1 MIMO antenna using FR4, and rubber substrate were measured and compared with other existing techniques. The proposed antenna can be used for future 5G smart phones achieving six 5G bands and about 7.5 dBi gain.

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## Declarations

**Conflict of Interest** No conflict of interest.

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