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Design of Parasitic Patch Integrated High Isolation Compact Super Wideband (26 GHz-50 GHz) MIMO Antenna for 5G Applications

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Multiple-input multiple-output (MIMO) antenna is a vital component to be used in fifth-generation (5G) communication systems to satisfy the requirements of high data rate and channel capacity for 5G technology. However, the antenna performances are proportionately degraded due to high mutual coupling interference between the antenna elements. This article presents a compact multi-resonant and super wideband MIMO antenna with high isolation characteristics for 5G mm-wave applications. Initially, a monopole antenna with wide band and very compact size was designed. Later, three ports MIMO antenna has been developed in order to satisfy the requirements for the 5G mm-wave applications. To improve the isolation among radiating elements, simple rectangular *L*-shaped and rectangular parasitic elements are graved between MIMO-element. The proposed configuration improves isolation less than – 20 dB for the desired operating band. The proposed FR-4 substrate based cost-effective MIMO antenna is well miniaturized with superior characteristics. The intended MIMO antenna design has a miniaturized dimension of (14.5 × 10.5 × 0.58 mm^3). All performance parameters are achieved through simulation using HFSS software. The presented MIMO antenna provides attractive performance in terms of miniaturized size, multi-resonant frequencies, super wideband operation, and high isolation characteristics. The suggested MIMO antenna operates covering a super wide band from 26 GHz to 50 GHz with high isolation of less than – 15 dB throughout the band of interest. The gain offered by the MIMO antenna varies in between 4 dBi to 6 dBi.

Keywords: MIMO antenna, Millimeter wave, Parasitic patch, Super wideband antenna, 5G applications.

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1. INTRODUCTION

In today's era, majority of high-speed wireless communication systems are based on 5G technology [1-3], due the reasons of high data rates and high channel capacity [4]. The sub 6 GHz (lower band) and millimeter-wave (higher band) frequencies are the choices for 5G communications. The main reasons for working on the mm-wave band for 5G applications are the fulfillment of some prime requirements in terms of high data rates, enormous operating bandwidth and miniaturization of the operating devices. However, the wireless communication systems operating at mm-wave suffers from propagation loss and path loss. To overcome these associated losses, MIMO antenna with enhanced bandwidth is highly demanded for the 5G technology. However, the major design issue in MIMO antenna is to minimize the mutual coupling between the radiating elements in MIMO configuration. For the fulfilment of this purpose, the different design methods are introduced in the reported literature to minimize the mutual coupling between elements of MIMO-antennas.

In [5], a compact, low-profile two-elements MIMO antenna of 30 × 15 × 0.25 mm^3 size is reported for 28 GHz 5G applications. It offers 6.4 GHz bandwidth high isolation between MIMO-element by implementing DGS technique. The design in ref. [6], presents a MIMO-antenna using single layer meta surface for mm-wave 5G applications. This configuration achieves a good gain of 10.27 dB but suffers from low operating bandwidth and complexity of geometry with large size of antenna. In [7], a dual band (28/38 GHz) mm-wave MIMO antenna is reported which consists of four-elements and has a size of (20 × 24 × 0.508 mm^3) and low bandwidth range from 27.6-28.6 GHz and 37.4-38.6 GHz. In [8], a four element-monopole antenna is formed to design a MIMO configuration for 5G mm-wave application. It operates with wide bandwidth of 9.23 GHz range from 22.43 GHz to 31.66 GHz. The reported MIMO antenna system suffers from low gain and larger size. In [9], a mm-wave four-rectangular patch antenna configuration is arranged to form a MIMO system for 5G mm-wave application with bandwidth of 2.5 GHz and isolation less than 20 dB. The design referred in [10] presents a novel method to improve

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the isolation of about – 25 dB for 5G UWB applications. The four ports MIMO system is proposed in ref. [11] which operates with multiband characteristics at mm-wave frequencies from 39-75 GHz with wide bandwidth and high isolation less than – 24 dB. This structure requires large antenna size for implementation and offers low gain. The design in ref. [12] present a four MIMO antenna using a parasitic patch to achieve high isolation between the MIMO-element. This antenna has an overall size of (28 × 28 × 0.79 mm^3) with high gain of 9 dB and 11 dB at 28 GHz and 38 GHz respectively. In [13] a review on a various technique is investigated to improve the isolation in MIMO antenna. The antenna structure in ref. [14], presents a MIMO array antenna configuration for 5G mm-wave applications with high gain of 12 dB. This antenna provides narrow bandwidth and large size (40 × 20 × 0.58 mm^3). In [15], a dual band DRA MIMO antenna is proposed with enhanced isolation. This antenna operates at 28 GHz and 38 GHz for 5G mm-wave applications with high isolation less than – 20 dB.

Considering the above reported limitation, we propose and discuss a very compact MIMO antenna system for operating at multiple resonant frequencies along with a super wide band frequency coverage to support 5G applications in the 26 GHz to 50 GHz mm-wave band. The proposed MIMO configuration consists of three monopole antennas placed on FR4 epoxy substrate. Parasitic patches of rectangular and *L*-shaped are loaded between MIMO-element to minimize the mutual coupling. The article is organized and presented as: The proposed single antenna and simulation results are presented in section II. While the MIMO antenna design and procedure is presented in section III. The simulation findings are discussed in section IV along with performance evaluation as compared to other reported works. Finally, the conclusion of the article is summarized in section V.

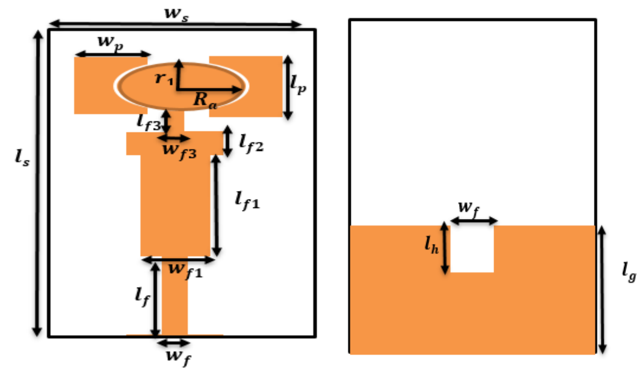
2. PROPOSED SINGLE WIDEBAND ANTENNA

2.1 Antenna Design and Procedure

The final wideband single antenna is demonstrated in Fig. 1. It consists of a modified rectangular patch connected with an elliptical patch. The rectangular DGS and partial ground plane are employed to obtain bandwidth enhanced wide band resonance. The main patch and parasitic patch are graved on a rectangular substrate of 0.58 mm FR4 epoxy. The structural dimension of the antenna is very compact (3.8 × 10 × 0.58 mm^3). The optimized parameters of the single element antenna are listed in Table 1.

2.2 Proposed Single Antenna Evolution

The formation of proposed single antenna through different design steps are shown in Fig. 2. The corresponding reflection coefficients of different stages are illustrated in Fig. 3. Initially, we started by a simple monopole antenna with elliptical radiator and full ground plane (stage1). This configuration resonates at 46.48 GHz

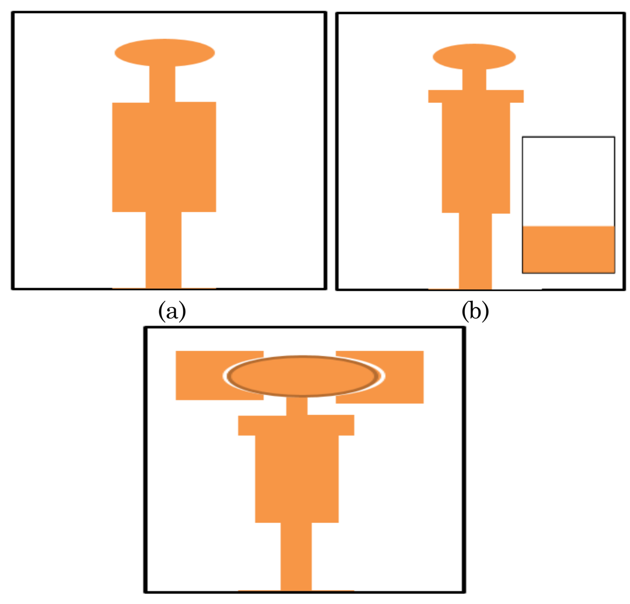


(a) **(b)**

Fig. 1 – Single antenna layout (a) side view (b) back view

Table 1 – Optimized dimensions of designed single wide band antenna

Parameters	Value(mm)	Parameters	Value(mm)
w_s	3.8	w_{f2}	2.8
l_s	10	l_{f2}	0.78
w_f	0.88	w_{f3}	0.22
l_f	3.2	l_{f3}	0.68
w_{f1}	2.28	R_a	0.33
l_{f1}	4	r_1	0.68
w_p	1.65	l_g	2.4
l_p	1.4	l_h	0.85



(a) (b) (c)

Fig. 2 – Stages evolution procedure of the single wide dual band antenna

with narrow bandwidth range of 43.26-47.5 GHz. After that, another rectangular patch is attached with the initial antenna with a partial ground plane to create another resonance frequency with wide bandwidth. The antenna at this design stage resonates from 27.15 GHz to 44.25

GHz. In stage 3, two rectangular parasitic patches are introduced around the elliptical patch to improve the antenna bandwidth. A rectangular DGS is introduced on the ground plane to attain an enhanced bandwidth. The proposed antenna operates from 26.64 GHz to 48.28 GHz with an impedance bandwidth of 21.64 GHz.

2.3 Simulation Results and Discussion

To analyze the behavior of proposed single antenna for 5G mm-wave applications, results in terms reflection coefficient, and peak gain are presented and discussed in this section. The simulated results for reflection coefficient of proposed single antenna are shown in Fig. 4 (a). The antenna operates at mm-wave frequencies with wide bandwidth of 21.64 GHz from 26.64 GHz to 48.28 GHz.

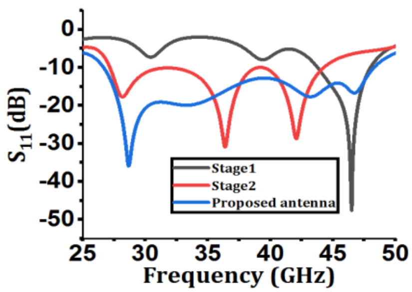
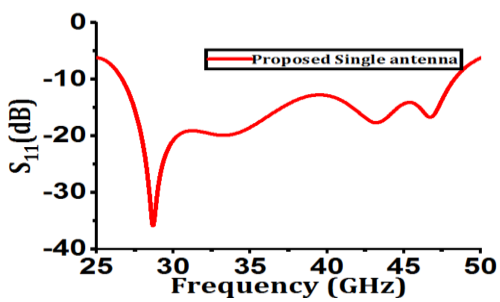
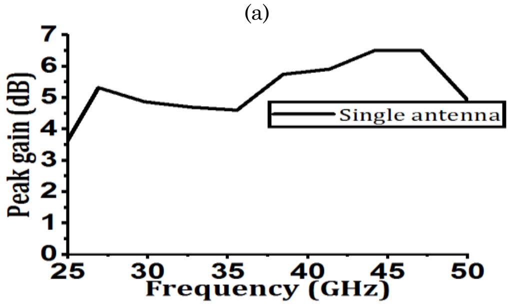


Fig. 3 – Reflection coefficient for different design stages of single element antenna



(a)



(b)

Fig. 4 – Proposed single element antenna (a) S_{11} (b) gain

The simulated peak gain is presented in Fig. 4(b). As observed, the gain varies from 4dBi to 6.5 dBi for the total band. Table 2 compares the proposed single antenna with other works in terms size, gain, type of substrate and bandwidth.

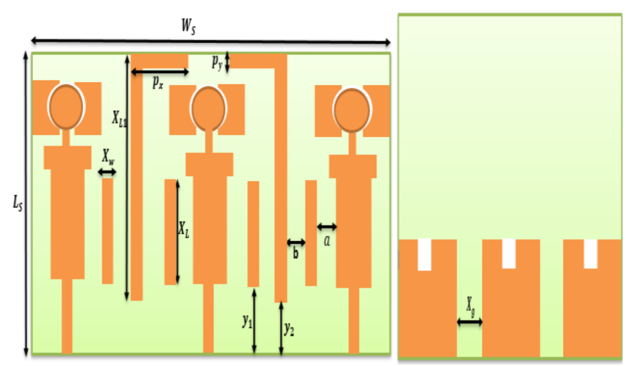
Table 2 – Performance analysis of single antenna with reported works

Ref.	Size (mm^3)	B.W (GHz)	Peak Gain (dBi)
[9]	8 × 8 × 0.889	2.5	7
[11]	8 × 14 × 1.6	36	6
[12]	13 × 15 × 0.508	5.5	7
[14]	10 × 6 × 0.254	1.7	–
[8]	12 × 10 × 0.254	9.52	3.5
This Work	3.8 × 10 × 0.48	21.64	6.5

3. MIMO ANTENNA CONFIGURATION

3.1 Design MIMO Antenna

Based on the geometry of the finalized single element, the intended structure of three element MIMO antenna system is configured. The proposed MIMO antenna is presented in Fig. 5. Parasitic elements are placed between the patch radiators to minimize the mutual coupling among them. The proposed MIMO occupies only 14.5 × 10.5 × 0.58 mm^3 space for implementation. The designed MIMO antenna operate at mm-wave spectrum with wide band (26 GHz to 50 GHz) with a super wide operating bandwidth of 24 GHz to support multiple wireless application bands for 5G applications. Furthermore, it has a very good isolation of higher than 15 dB and minimum gain of greater than 4.5 dBi for the entire operating bandwidth. The optimized dimensions of our structure are given as: W_s = 14.5; L_s = 10.5; X_w = 0.6; X_L = 3.7; X_{L1} = 7.9; P_x = 1.5; P_y = 0.3; Y_1 = 3; Y_2 = 2.6; X_g = 1.55; a = 0.46; b = 0.2 [All dimensions are in mm]

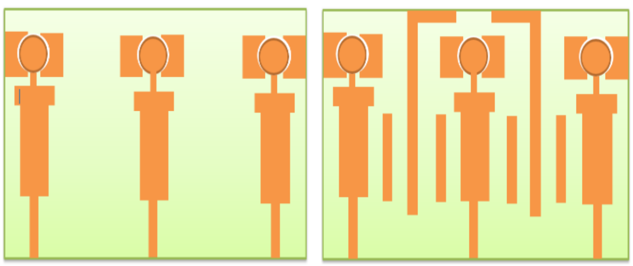


(a) (b)

Fig. 5 – Proposed MIMO antenna (a) bottom view (b) back view

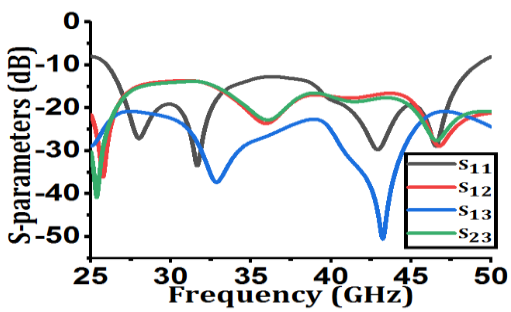
3.2 MIMO Antenna Evolution Design and Improvement of Isolation

The design steps to finalize the required compact MIMO antenna are shown in Fig. 6. In the first step, we placed three monopole antennas on FR4-epoxy substrate of 14.5 × 10.5 mm^2. Fig. 7 (a) illustrates the S-parameters response of the first design and the response for proposed design is shown in Fig. 7 (b). The demonstrated results indicate that the antenna without parasitic patches operate from 26-48.5 GHz with wide band of 22.5 GHz. However, the design suffered from high mutual coupling. In order to improve the coupling between the patch-elements, parasitic elements are loaded between the monopole antenna elements as referred in second design step. The parasitic element integrated MIMO antenna configuration leads to maximization of the isolation > 15 dB. The isolation characteristic parameters are noticeably improved by 6 dB offering isolation of greater than 20 dB over a wider operating band ranging from 32 GHz to 50 GHz. Also, slight improvements in operating bandwidth are observed compared to the design case without parasitic patch elements.

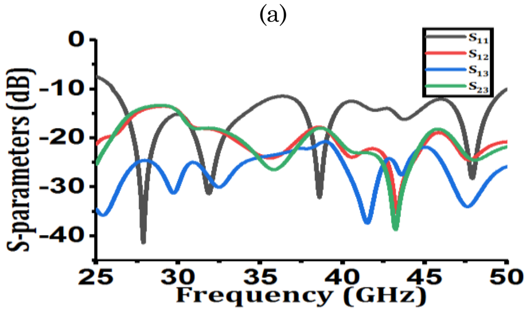


(a) (b)

Fig. 6 – Evolution design of MIMO configuration (a) step 1 – without parasitic patch (b) with parasitic patch



(a)

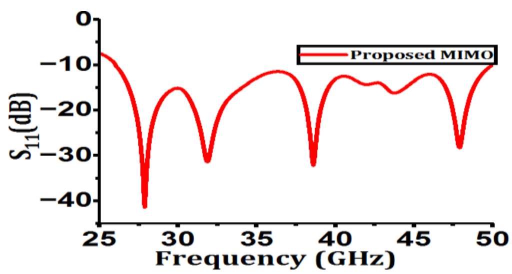


(b)

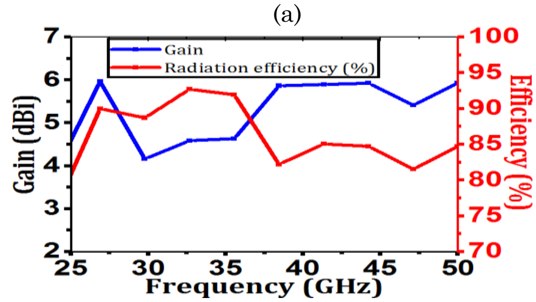
Fig. 7 – Reflection coefficient of (a) step1 – without parasitic patch (b) proposed MIMO antenna with parasitic patch

4. RESULTS AND DISCUSSION

The MIMO antenna is analyzed by simulated results in terms various characteristics such as *S*-parameters (reflection coefficient and isolation parameters), gain and radiation patterns. The final geometry has a very compact overall size of (W_s = 14.5 mm, L_s = 10.5 mm, h_s = 0.58 mm). The S_{11} result is depicted in Fig. 8 (a) that suggests the proposed antenna operates at multiple resonant frequencies (28, 32, 38, and 48 GHz) within the operating band (26-50 GHz) with a super wide bandwidth of 24000 MHz. Furthermore, the MIMO antenna maintains very high isolation characteristics although having very compact antenna dimension. Fig. 8 (b) presents the gain and radiation efficiency. The antenna offers maximum gain of 6 dBi, and radiation efficiency of above 90 % over the desired operating bandwidth. The major diversity parameter, envelope correlation coefficient (ECC) is found to be less than 0.010 as indicated in Fig. 9. The well-defined value of ECC within acceptable limit of 0.5 indicates superior diversity performance of the prescribed MIMO antenna. The radiation patterns of the MIMO antenna are shown in Fig. 10. The proposed antenna maintains omnidirectional radiation patterns, which is required for intended 5G applications.



(a)



(b)

Fig. 8 – Proposed MIMO antenna (a) S_{11}-parameter (b) gain & radiation efficiency

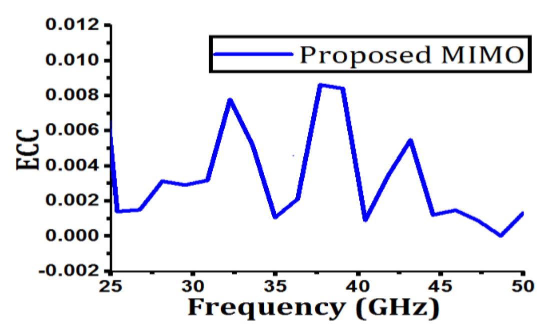
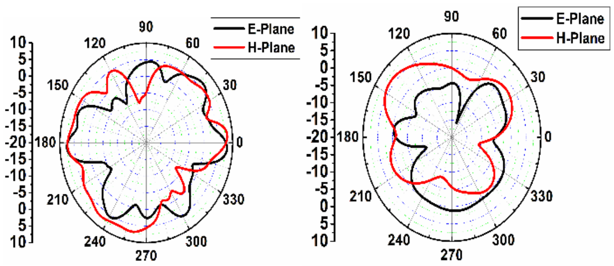


Fig. 9 – ECC vs Frequency plot of the MIMO antenna



(a) (b)

Fig. 10 – *E-H* Plane radiation patterns at (a) 28 GHz (b) 48 GHz

Table 3 – Performance comparison

Ref.	Size (mm³)	B.W (GHz)	Peak Gain (dB)	Isolation (dB)
[7]	20 × 24 × 0.508	1	7.9	28
[8]	24 × 24 × 0.254	9.23	5.66	25
[9]	13 × 14 × 0.88	2.16	5.5	24
[11]	36 × 36 × 1.6	36	5.38	24
[12]	28 × 29 × 0.79	5	9.5	15
This Work	14.5 × 10.5 × 0.58	24	6.0	15

Table 3 presents the performance comparison of the proposed MIMO antenna with a few other reported works in literature, operating in mm-wave frequency band. Likewise other reported works, the proposed antenna also offers well acceptable performance in terms of small size, enhanced bandwidth, high isolation and radiation performance. These confirm the candidature of the suggested MIMO antenna for 5G mm-wave applications.

5. CONCLUSION

In this article, a very compact multiband and super wide band MIMO antenna is proposed for 5G mm-wave applications. The proposed configuration is composed of three monopole antennas whose ports are arranged in a parallel position on FR4-epoxy substrate. The proposed MIMO antenna operates with multiple resonances at 28 GHz, 32 GHz, 38 GHz and 48 GHz with wide bandwidth of 24 GHz that ranges from 26 GHz to 50 GHz. In addition, the proposed MIMO antenna has a maximum element-isolation of – 48 dB due to suggested antenna geometry loaded with parasitic patch elements. On the other hand, the proposed antenna has a compact size of (14.5 × 10.5 × 0.58 mm³) and good gain between 4 dBi and 6 dBi. Thus, the compact size, simple geometry, good isolation, good radiation performance, multiband and wide band confirms that proposed MIMO system is suitable for 5G millimeter-wave applications.

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Конструкція паразитного патча інтегрованої компактної з високою ізоляцією надширокосмугової (26 ГГц-50 ГГц) MIMO антени для програм 5G

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Антена з декількома входами та декількома виходами (MIMO) є важливим компонентом для використання в системах зв'язку п'ятого покоління (5G), щоб задовольнити вимоги високої швидкості передачі даних і пропускної здатності каналу для технології 5G. Однак характеристики антени пропорційно погіршуються через високі взаємні перешкоди між елементами антени. У цій статті представлено компактну мультирезонансну та надширокосмугову антену MIMO з високими характеристиками ізоляції для додатків 5G мм-хвиль. Спочатку була розроблена монопольна антена з широким діапазоном і дуже компактними розмірами. Пізніше була розроблена антена MIMO з трьома портами. Для покращення ізоляції між випромінюючими елементами, прості прямокутні *L*-подібні та прямокутні паразитні елементи врізані між MIMO-елементами. Запропонована конфігурація покращує ізоляцію менше ніж на – 20 дБ для робочого діапазону. Запропонована рентабельна мініатюризована MIMO антена на підкладці FR-4, конструкція якої має мініатюрний розмір (14.5 × 10.5 × 0.58 mm³). Усі параметри продуктивності досягаються шляхом моделювання за допомогою програмного забезпечення HFSS. Представлена MIMO антена забезпечує привабливі характеристики з точки зору мініатюрних розмірів, мультирезонансних частот, надширокосмугової роботи та високих характеристик ізоляції. Антена працює в надширокій смузі від 26 до 50 ГГц з високою ізоляцією менше, ніж – 15 дБ по всій смузі інтересів. Коефіцієнт посилення антени MIMO коливається від 4 до 6 дБ.

Ключові слова: MIMO антена, Широкосмугова антена, Міліметрова хвиля, Паразитна ділянка, Програми 5G.