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A Compact Multi-resonant Wide Band MIMO Antenna for 5G Communication Systems at mm-wave Band

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In this paper, a novel compact dual-wide band multiple input multiple output (MIMO) antenna system with a better performance for 5G communications systems at mm-wave frequencies (28/38 GHz) is presented. Firstly, a single element was designed and detailed to resonate at mm-wave band frequencies (28/38 GHz). The basic antenna is a simple circular patch that resonates at 38 GHz. In order to generate the second operating frequency of the proposed antenna, two rectangular inverted L-shaped slots are introduced (Ant II). Furthermore, to improve the impedance matching at desired frequencies, a circular slot is introduced on the radiating element (Ant III). Two inverted F-shaped and rectangular DGS are inserted on the ground plane to improve the operating bandwidth of the antenna (proposed single element antenna). A low-cost substrate FR4-epoxy having a relative constant 4.4, loss tangent of 0.02 and thickness of 0.74 mm is used in this design. The simulated result shows the proposed single antenna has the better performances. The single antenna has a compact size of $7 \times 6.8 \times 0.74$ mm^3. Furthermore, the two single elements are transformed into 2-port MIMO configuration for mm-wave 5G MIMO applications. To achieve the improved isolation characteristic of the MIMO antenna, a rectangular DGS is introduced in the center of the ground plane. The result indicates that this antenna shows a reflection coefficient under – 10 dB over a range from 26.82 GHz to 38.16 GHz with bandwidth of 11.34 GHz (F.B.W 34.90 %). The gain of the antenna is found more than 5 dB in the whole operating band width. The MIMO antenna is also characterized by good isolation ranging from 19 to 56 dB. Additionally, the MIMO antenna has a compact size of $15.5 \times 6.8 \times 0.74$ mm^3. Due to these superior results, the proposed MIMO antenna could be a potential candidate for MIMO 5G mm-wave applications.

Keywords: MIMO antenna, mm-wave, DGS, Wide bandwidth, 5G applications.

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1. INTRODUCTION

Today, MIMO antennas with low profile compact size, multiband, wide band, high gain and high isolation characteristics are highly demanded to satisfy the necessities of modern wireless communication systems. To realize high data rate and bandwidth requirements, the US federation communication commission (FCC) assigned the millimeter wave frequency range 24-60 GHz for 5G applications. Printed 5G antennas has become the center attraction for 5G mm-wave applications due to its low cost, compact size and higher data rate. However, this antenna suffered by various limitations such as path loss attenuation, signal fading, and atmospheric absorption. To solve these problems, research is centered on MIMO systems based on Multiple Input Multiple Output (MIMO) antenna configuration. This antenna technology is also used to enhance the channel capacity and multipath propagation. However, these antennas suffered from serious mutual coupling between different ports of the MIMO systems. In previous studies, various techniques have been used to reduce the mutual coupling and to improve the performance characteristics of MIMO antenna. In [1], a compact four ports MIMO antenna resonating at 28/38 GHz with a impedance bandwidth of 1.06 GHz at 28 GHz and 1.43 GHz at 38 GHz along with a mutual coupling of – 28.32 dB at 28 GHz and – 26.27 dB at 38 GHz is presented. In [2], two port dual band MIMO antenna with a compact dimension of $15.3 \times 8.5 \times 0.79$ mm^3 for 28/38 GHz operation is presented. In [3], a compact dual band MIMO antenna at 28/38 GHz with circulation polarization is presented and it shows gain of 7.6 dB at 28 GHz and 8.12 dB at 38 GHz. In [4], a dual band two port MIMO antenna is presented which shows gain of 8.4 dB at 28 GHz and 6.02 dB at 38 GHz. It operates with 9.42 % and 5.77 % fractional bandwidths at 28 GHz and 38 GHz. In [5], four ports-

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MIMO antenna is considered for 28/38 GHz 5G applications having an overall size of ($25 \times 30 \times 0.8$ mm^3). It offers a wide bandwidth of 13.68 GHz for S11 < – 15 dB. The 4-ports MIMO antenna referred in ref. [6] achieves a wide bandwidth from 23-40 GHz with a high gain of 10.58 dB at 28 GHz and 11.45 dB at 38 GHz. In [7], the MIMO antenna with four-element configuration is presented with an overall size of $47.432.5 \times 0.51$ mm^3 that offers high isolation but at the cost of low gain, low operating bandwidth and single resonance frequency. In [8], the four-Hexagonal elements based MIMO antenna operates at 35 GHz for 5G applications and it suffers from low gain, single resonance frequency and low operating bandwidth. The CPW fed 4-ports MIMO antenna with a connected ground is presented in [9]. It offers an isolation > 20 dB, operates from 24.8 GHz to 44.45 GHz with a peak gain of 6.08dB and an overall size of $24 \times 24 \times 0.58$ mm^3.The MIMO antenna consists of a triplet shaped ring surrounded by an infinity-shaped shell is presented in [10]. This structure provides high ports isolation of greater than 29 dB and high gain of 6.1 dB. But it offers low operating bandwidth and single resonance frequency. The work in [11] reported a 4-port MIMO antenna to offer high isolation using the EBG and DGS network decoupling. The peak gain reaches to 12.02 dB and it offers limited bandwidth of 1GHz at single operating band centered at 28 GHz. In [12], a compact $29 \times 49 \times 1.6$ mm^3 multiband MIMO antenna is presented using a rectangular zigzag shaped slots and it achieves an isolation of greater than 30 dB. In [13], a proximity coupled MIMO antenna operates at 28 GHz for 5G mm-wave application with a compact size of 8.0×8.0 mm^2 with improved mutual coupling of less than – 24 dB. Other than MIMO configurations, researchers have also proposed single element based printed antennas for 5G applications [14-16].

This work has been carried out with two major goals. The first goal is focused on the design of single element wide band antenna with multi-resonance, high gain and compact size and the second goal is focused on the design of a 2-port MIMO configuration with high isolation, high gain, wide impedance bandwidth, and muti-resonant operating frequencies.

2. ANTENNA DESIGNS

2.1 Compact Single Element Antenna

In this section, a detailed study on the geometry of the proposed single element wideband antenna has been presented. The geometry of this suggested antenna is shown in Figure1. The proposed configuration of the single element antenna is designed on a low-cost substrate FR4-epoxy having a relative dielectric constant of 4.4, loss tangent of 0.02 and thickness of 0.74 mm. It has a compact size of $7 \times 6.8 \times 0.74$ mm^3.

Design and optimization of the proposed basic antenna has been performed through a parametric analysis in ANSY HFSS. The optimized dimension of the compact single wide dual-band antenna is listed in Table 1.

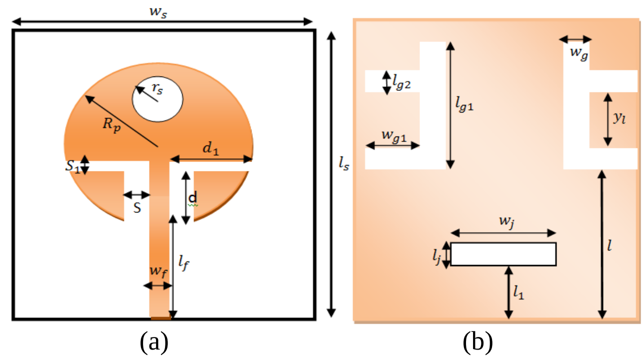


Fig. 1 – Proposed single antenna (a) side view (b) back view

Fig. 2 presents the different steps to examine performance of the proposed antenna. The antenna evolution procedure is divided into four major steps.

- Initially, a conventional circular patch antenna operating at 37.8 GHz was designed (step 1).
- Next, to create the second band at 28 GHz, two rectangular slots are introduced on the tope side of the radiator element (step 2).
- To improve the impedance matching at 28/38 GHz, next circular slot was introduced on the radiator patch (step 3).
- In order to meet the wideband characteristics, two inverted F-shaped DGS and rectangular DGS are introduced in ground plane as referred in step 4 (proposed antenna).

Table 1 – Optimized dimensions of proposed single element wide band antenna

Component	Parameters	Values (mm)
patch	R_p	2
	h_p	0.035
Substrate	w_s	6.8
	l_s	7
Feed line	w_f	0.62
	l_f	2.3
Rectangular slot	s_1	0.1
	d_1	1.7
	S	0.18
	d	1.84
Circular slot	r_s	0.68
F-shaped DGS	w_g	3
	l_{g1}	3
	l_{g2}	0.36
	w_{g1}	1.2

The simulated results of the different evolution steps are illustrated in Fig. 3. In the first step (step 1), the conventional circular patch antenna operates at 37.3 GHz with a S_{11} of – 34 dB along with an operating bandwidth of

2.15 GHz. On the other hand, in step 2, two more additional resonances are generated with an improvement in operating bandwidth due to the insertion of two rectangular slots. In this step, the antenna shows dual operating bandwidth from 27.8 to 32.8 GHz and from 37 to 39.6 GHz. Then, in step 3, a circular slot of radius, $R_p = 2$ mm is inserted on the patch layer that improves the impedance matching in the desired frequency band (28/38 GHz) and also maintains wide operating dual bandwidths. Finally, in order to enhance the operating bandwidth and gain of the proposed antenna, two identical inverted F-shaped DGS and rectangular DGS are etched at the ground plane (step 4). In this design step, the proposed antenna operates at triple resonances centered at 28 GHz, 32 GHz, and 38 GHz with a single wide impedance bandwidth from 26.99 GHz to 38.83 GHz, which is 11.84 GHz with a fractional percentage bandwidth of 35.97 %. The gain variations for the proposed single element antenna are displayed in Fig. 4. The peak gain of the antenna is 7.36 dB at 28.44 GHz.

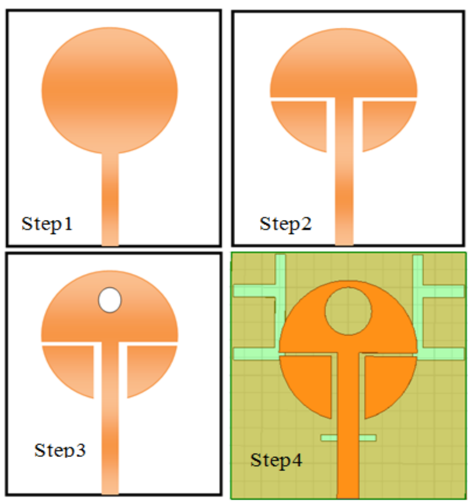


Fig. 2 – Steps development procedure of the single wide dual band antenna

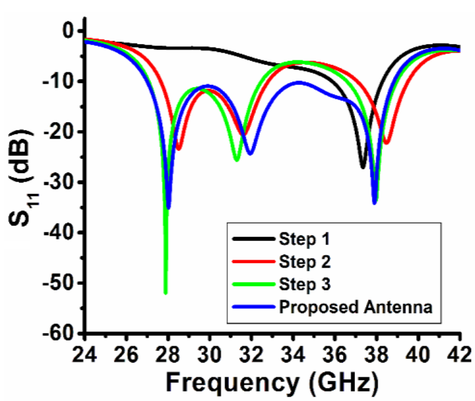


Fig. 3 – Reflection coefficients for different steps

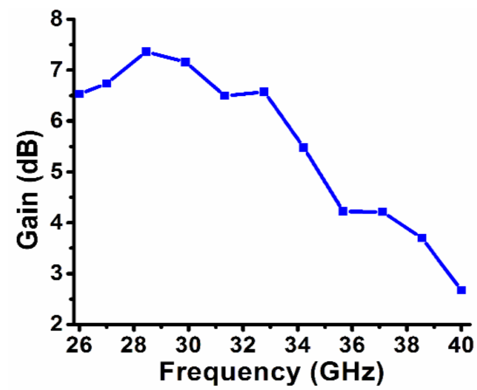


Fig. 4 – Peak gain vs frequency of single antenna

3. MIMO ANTENNA CONFIGURATION

The main goal in this work is to design a compact wide- band MIMO antenna with high isolation and improved gain for 5G MIMO mm-wave applications. The geometry and optimized parameters of the proposed MIMO configuration is presented in Fig. 5. The top plane of the proposed two-element MIMO antenna is based on identical patch element of single antenna. The bottom plane is configured with defected ground plane structure. The MIMO structure is designed and optimized using 0.74 mm thick FR-4 substrate with the help of HFSS software. The MIMO antenna system having a compact overall size of $15.5 \times 6.8 \times 0.74$ mm^3, operate from 26.82 GHz to 38.16 GHz with a wide bandwidth of 11.34 GHz.

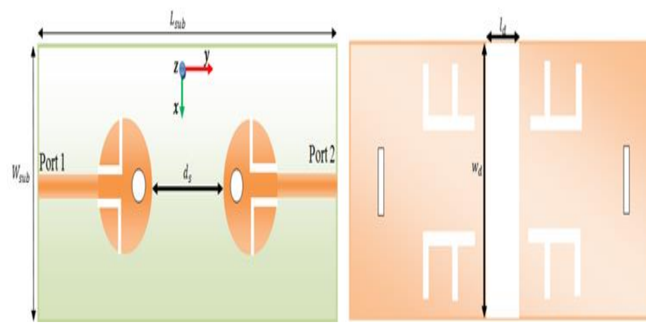
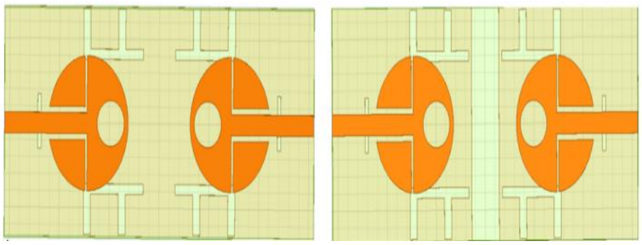


Fig. 5 – Configuration of proposed MIMO antenna, top view and back view

3.1 MIMO Antenna Design Steps

In this part, the MIMO antenna design steps and analysis is presented. Fig. 6 shows the two major steps to develop the proposed MIMO antenna. Initially, two single elements which are designed in the first section are placed on the tope side of thin FR4 epoxy substrate of 0.74 mm thickness. To improve the isolation between two ports MIMO antenna, a rectangular slot is introduced on the center of the ground plane along with four F-shaped DGS. The optimized length and width of the rectangular DGS are 1.4 mm and 6.8 mm, respectively.



Step 1 Step 2

Fig. 6 – MIMO configuration step 1, step 2 (proposed MIMO antenna)

Fig. 7 shows the S-parameters comparison of these two deign evolution steps (Step 1 and Step 2). It can be seen that both configurations offer similar operating bandwidth but the proposed MIMO antenna (step 2) provides desired resonant frequency at higher operating band with much better return loss characteristics. Also, the proposed MIMO antenna (step 2) shows a significant improvement in isolation (S_{12}) compared to the first step due to the suggested modifications in the ground plane structure. In step 1, without DGS decoupling, the isolation is achieved from 14 dB to 38 dB. However, the proposed MIMO antenna with DGS decupling has high isolation from 19 dB to 56 dB on the desired band. The peak isolation is improved by 18 dB.

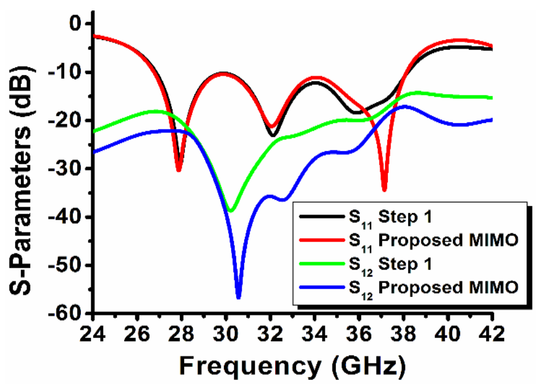


Fig. 7 – S-parameters comparison between step1 and proposed MIMO antenna

3.2 Results and Discussion

The results of the proposed MIMO antenna are analyzed and discussed in terms reflection coefficient, gain and radiation patterns. Fig. 8 presents the reflection coefficient (S11) and isolation (S12) characteristics of the proposed MIMO antenna versus frequency. It operates at triple resonant frequencies with a wide – 10 dB impedance bandwidth of 11.34 GHz (26.82 GHz to 38.16 GHz) for 5G MIMO applications. The proposed antenna offers superior isolation characteristics with a maximum isolation of 56 dB. Fig. 9 shows the gain variation results of the two-element MIMO antenna. The peak gain of the antenna is 8.07 dB at 28.44 GHz and the antenna maintains an average gain above 6 dB throughout the entire operating band. Fig. 10

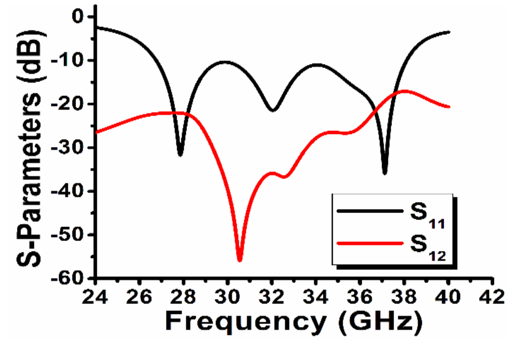


Fig. 8 – S-parameters of proposed MIMO antenna

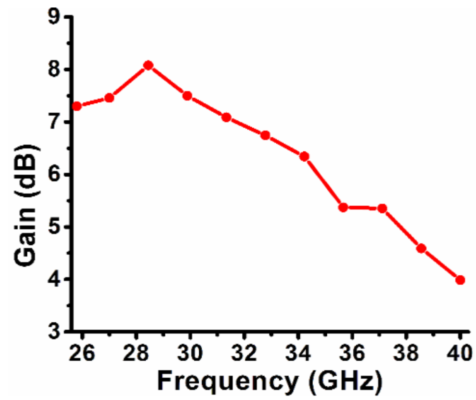
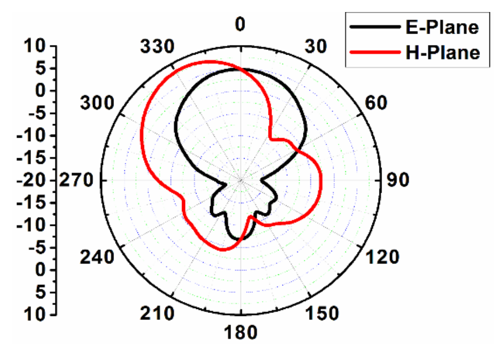
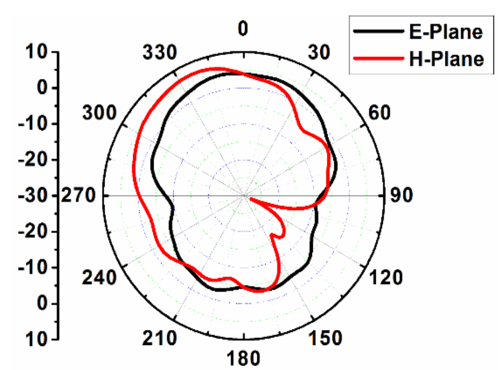


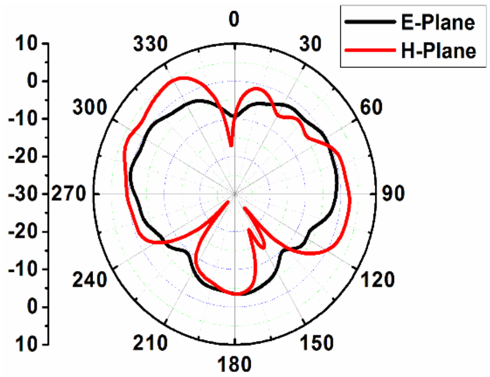
Fig. 9 – Gain versus frequency of proposed MIMO antenna



(a)



(b)



(c)

Fig. 10 – Radiation patterns of proposed MIMO antenna (a) 28 GHz, (b) 32 GHz, (c) 38 GHz

shows the 2D radiation patterns in E-plane (Phi = 0 deg) and H-plane (Phi = 90 deg) for the proposed MIMO antenna system at three different operating frequencies. From the displayed Figures, it can be concluded that the proposed antenna exhibits a directional radiation pattern in *E*-plane and *H*-plane at 28 GHz. But, with the increase in frequency, the directional characteristics of the antenna changes and it shows nearly an omnidirectional radiation pattern in both the planes at 38 GHz.

3.3 Performances Comparison

Table 3 shows the performance comparisons of the proposed MIMO antenna in terms of size, bandwidth, gain and isolation with some other works reported in literature. It is clearly observed from the table that the proposed MIMO antenna has most compact size, triple resonant frequencies, and highest isolation. Additionally, the proposed MIMO antenna also has wideband operation and very good gain. So, the performance of the proposed MIMO antenna is comparable with other previously published works.

Table 2 Performances comparison

	Reso-nant Fre. (GHz)	Antenna Size (mm^3)	Band width (GHz)	Peak Gain (dB)	Isolation (dB)
[1]	28/38	55 × 110 × 0.508	–	8.27	4.6
[3]	28/38	75 × 100 × 0.508	0.7/12	8.12	36
[4]	28/38	14 × 14 × 0.8	2.4/2	8	25
[5]	28/39	25 × 30 × 0.8	13.6	7.49	20
[6]	30	80 × 80 × 1.57	17	12	20
[9]	28/38	24 × 24 × 0.8	19.6	8.6	20
[10]	28	30 × 30 × 0.787	2	6.1	29
[13]	28	13 × 14.5 × 0.889	2.16	6.55	24
This Work	28/32/38	15.5 × 6.8× 0.74	11.34	8.07	56

4. CONCLUSION

A new compact multi-resonant wide band MIMO antenna for 5G mm-wave applications (28/38 GHz) is presented. Initially, a single element wide band antenna is designed and its characteristics performance is improved using DGS and slot techniques. Then, the proposed single antenna is placed into 2-port two-element MIMO configuration. The performance of the proposed MIMO antenna is improved by introducing DGS in the ground plane. With this configuration, the proposed MIMO antenna provides better performances, high gain, very good isolation, triple resonant frequencies, and wide bandwidth in a compact size. Thus, this MIMO antenna is a potential candidate for mm-wave 5G applications.

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Компактна мультирезонансна широкосмугова MIMO-антена для систем зв'язку 5G у мм-діапазоні хвиль

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У цій статті представлено конструкцію нову компактну двосмугову антенну систему з багатьма входами і виходами (MIMO) з кращою продуктивністю для систем зв'язку 5G на частотах міліметрових хвиль (28/38 ГГц). По-перше, один елемент був розроблений і деталізований для резонанса на частотах мм-хвиль (28/38 ГГц). Основна антена - це проста кругла ділянка, яка резонує на частоті 38 ГГц. Для генерації другої робочої частоти запропонованої антени введено два прямокутних перевернутих L-подібних щілини (Ant II). Крім того, щоб покращити узгодження імпедансу на бажаних частотах, на випромінювальному елементі введено круглий проріз (Ant III). Два перевернутих F-подібних і прямокутних DGS вставлені на заземлену площину для покращення робочої смуги пропускання антени. У цій конструкції використовується недорога підкладка FR4-епоксидна смола з відносною константою 4,4, тангенсом втрат 0,02 і товщиною 0,74 мм. Змодельований результат показує, що запропонована одна антена має кращі характеристики. Одинарна антена має компактні розміри 7×6,8×0,74 мм^3. Крім того, два окремих елемента перетворюються на 2-портову конфігурацію MIMO для додатків 5G MIMO міліметрових хвиль. Для досягнення покращених характеристик ізоляції антени MIMO, у центрі заземленої площини введено прямокутний DGS. Результат показує, що ця антена демонструє коефіцієнт відбиття нижче -10 дБ у діапазоні від 26,82 ГГц до 38,16 ГГц із смугою пропускання 11,34 ГГц (FBW 34,90%). Коефіцієнт посилення антени становить понад 5 дБ у всій робочій смузі. Антена MIMO також характеризується хорошою ізоляцією в діапазоні від 19 до 56 дБ. Крім того, антена MIMO має компактний розмір 15,5×6,8×0,74 мм^3. Запропонована антена MIMO може бути потенційним кандидатом для додатків MIMO 5G міліметрових хвиль.

Ключові слова: MIMO антенна, Міліметрові хвилі, DGS, Пропускна здатність, 5G застосування.