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High Isolated Compact 2x2 MIMO Antenna with DGS Decoupler for 5G/WLAN Application

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Abstract

In this article, a compact, square-shaped, 2x2 Multiple Input- Multiple Output (MIMO) antenna is presented for 5G/ WLAN application. The proposed antenna consists of four rectangular patch elements with modified T-shaped strip line structure on either side. Orthogonal Orientation Technique is employed as the primary decoupling technique to achieve acceptable isolation. Introduction of Defective Ground Structures (DGS) in the ground plane further enhances the isolation to 60dB. The antenna is resonating at 4.82 GHz. With enhanced MIMO metrics like ECC, Diversity Gain (DG), this antenna is apposite for 5G/ WLAN gadgets.

1. Introduction

In recent years, wireless communication has seen a sharp increase in the amount of data used. Among the different cellular networks, 5G mobile network technology has an edge over other network technology offering low latency, faster speed, higher bandwidth to name a few. While implementing 5G specifications, Multiple Input-Multiple Output (MIMO) Technology has proved to be better among other antenna technology [1]. MIMO systems constructed on patch antennas have attracted much attentions from researchers due to their attractive attributes of light weight, simple profile, and manageable structures [2].

MIMO technology reduces multipath fading and increases data transmission capacity when compared to single antenna systems. But designing a MIMO antenna for 5G implementation poses difficult task for the reason that mutual coupling and the isolation is affected due to the proximity of the radiating elements [3]. To address such factors, the most common approach is to increase the distance between the radiating elements which will provide less interference but at the expense of greater surface area. Thus, intensive research works are going on to design a compact MIMO antenna with high isolation and satisfactory MIMO metrics.

Employing Defective Ground Structures (DGS) as a suppression method has been extensively researched and implemented with an aim to suppress coupling effects [4], [5], [6]. However, it is noteworthy that using DGS structures increase backward radiation. Additional coupling paths to counteract original coupling which includes neutralization lines, parasitic elements or decoupling networks in [7], [8], [9] can also be used but substantially rises the complication and sizes of the MIMO systems. Placing adjacent radiating elements in orthogonal fashion is employed to diminish mutual coupling and enhance isolation between antenna components without using any decoupling structure [10], [11], [12]. Furthermore, the utilization of a metamaterial-based superstrate unequivocally collimates the radiated waves from the patch antenna, thus significantly sharpening the radiation patterns. [13]. However, metamaterial structures may not be suitable for contemporary compact device designs due to their bulky structure and difficult to design, analysis and fabricate heavy and complex structures.

In this paper, we propose a compact, low profile, isolation-enhanced DGS integrated 4 port MIMO antenna for 5G/ WLAN Application. The incorporation of DGS in the proposed antenna further reduces the mutual coupling among the MIMO elements. Along with discussing the scattering matrix analysis, this paper also covers MIMO metrics, including ECC and Diversity Gain, for comprehensive study.

2. Antenna Configuration

The proposed 2x2 MIMO antenna is printed on a FR-4 substrate (FR4 =4.4, h=1.6mm). All of the 4 elements with identical structure are placed at four corners of the substrate. The overall antenna structure is in square shape. The top and bottom view of the proposed antenna is shown in Figure 1(a) and Figure 1(b). Any two adjacent radiating elements are in orthogonal orientation. Initially, a significant isolation is achieved (50 dB) among the radiating elements by this orthogonal orientation technique. Additionally, a series of defective ground structures using dumbbell- shaped designs are incorporated on the ground in a manner so that they lie between the two adjacent radiating elements as shown in Figure 1 (c). This series of dumbbell-shaped DGS structures enhance the isolation and leads to an increase in antenna gain. The dimension of the proposed antenna is optimized through parametric study and is depicted in Table 1. Ansys High-Frequency Structure Simulator (HFSS) is used for the MIMO antenna simulation.

Table 1. Dimensions of Proposed 2x2 MIMO Antenna

Parameters	L_S	W_S	L_P	W_P	l_{st1}	W_{st1}	l_{st2}	W_{st2}
Values(mm)	40	40	5.5	5.5	9	0.5	1	0.5
Parameters	F_X	F_Y	L_B	W_B	L_D	l_1	w_1	l_2
Values(mm)	10	7.7	15.6	4	15.6	3	1	3
Parameters	w_2	D_1	D_2					
Values(mm)	0.5	3.2	26.25					

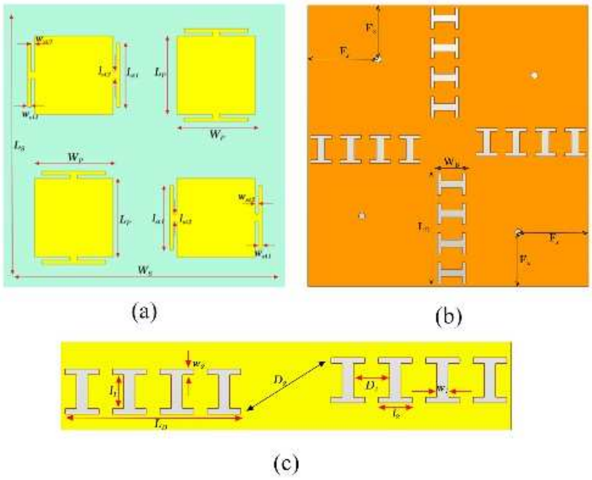

Figure 1. Geometry of proposed antenna (a) Front View (b) Back View (c)Dumbbell-shaped DGS structure

3. Design Process of the Proposed Antenna

This segment deals with various evolution stages to have the final design of the proposed antenna. From a single radiating element to multi-element radiating structures are individually discussed exploring S-parameters.

3.1 Analysis of Single Radiating Element

Initially, a single radiating element is considered of dimension 5.5x5.5 mm^2. Coaxial feed mechanism is used here to excite the radiator. Furthermore, to get the desired resonance at 4.8 GHz, T shaped strip lines are added on either sides of the patch as shown in Figure 2. This single element antenna is ultimately used as the individual radiator of the proposed 2x2 MIMO antenna. Figure 2 (c) illustrates the change in resonant frequency resulting from the modification of the patch.

3.2 1x2 MIMO Antenna Analysis

The evolution process of the proposed 2x2 MIMO antenna is initiated with the consideration of 1x2 radiating elements. The elements are placed both in linear and orthogonal orientation as shown in Figure 3 and their performance is analyzed.

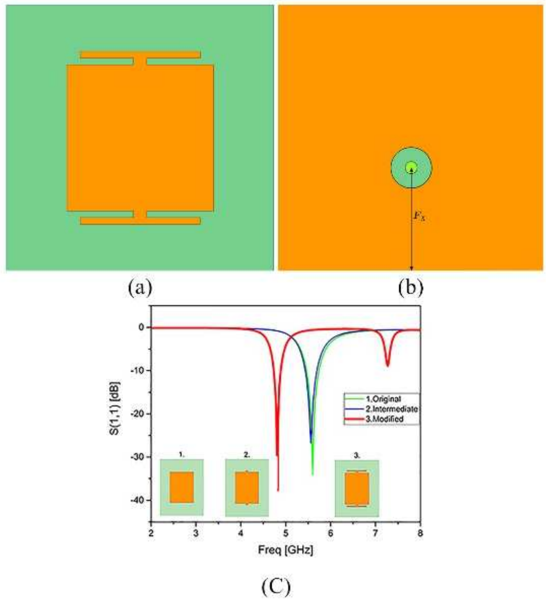

Figure 2. Single Radiating Element (a) Back View (b) Front View (c) Reflection-coefficient (S_{11})

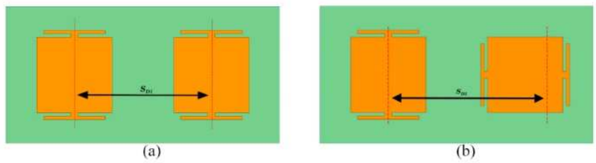

Figure 3. (a) Linear Orientation (SD1=20mm) (b) Orthogonal Orientation (SD2=22.44mm)

A substantial boost in the transmission coefficient and reflection coefficient values at resonant condition while employing orthogonal orientation is evident as shown in Figure 4.

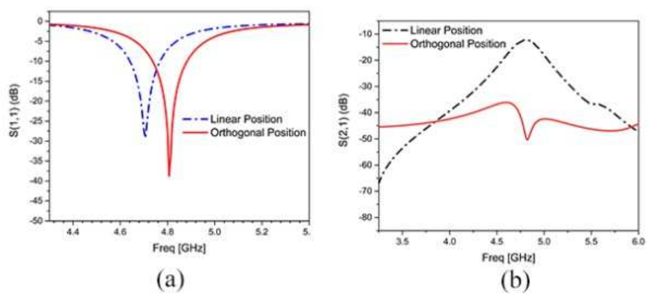

Figure 4. Two element MIMO characteristics (a) Reflection-coefficient (S_{11}) (b) Isolation

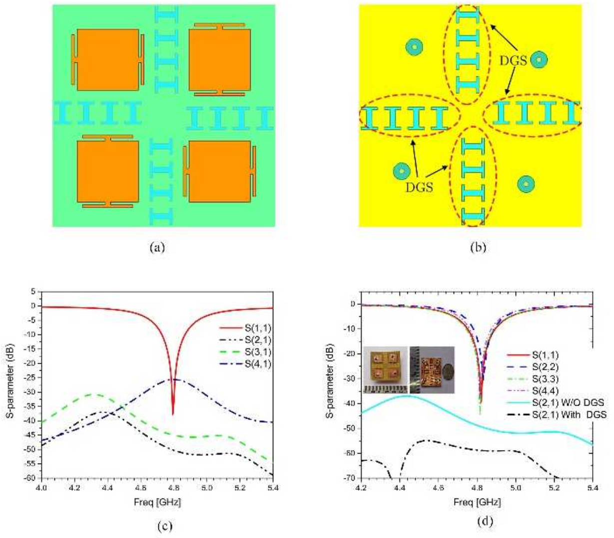

Figure 5. (a) 2x2 MIMO antenna with DGS (b) S-parameter (c) S_{21} with and without DGS

3.3 2x2 MIMO Antenna Analysis

Figure 5(a) and Figure 5(b) and represents the front and back view of the proposed DGS integrated 2x2 MIMO antenna. The reflection and transmission coefficient characteristics of the proposed antenna are shown in Figure 5(c) and Figure 5(d). It is evident from the Figure 5 that the incorporation of the DGS structure enhances the isolation to 60.19 dB.

4. MIMO Metrics

The S-parameters, radiation pattern, and diversity gain parameters are analyzed to verify the performance of the proposed 2x2 MIMO antenna.

4.1 Envelope Correlation Coefficient (ECC)

The ECC is related to the antenna correlation. Value of ECC must be less than 0.5 dB. Equation (1) shows the calculation of ECC to improve accuracy from far field radiation, where i & j = 1,2 for two-port element [3].

$$ECC(\rho_{ij}) = \frac{\iint_{4\pi} |\overline{F}_i(\theta,\phi).\overline{F}_j(\theta,\phi)d\Omega|^2}{\iint_{4\pi} |\overline{F}_i(\theta,\phi)|^2 d\Omega \iint_{4\pi} |\overline{F}_j(\theta,\phi)|^2\, d\Omega} \quad (1)$$

The ECC of proposed MIMO is in the order of 10^{-4} dB at 4.82 GHz, as shown in Figure 6.

4.2 Diversity Gain (DG)

In wireless systems, the quality and reliability of a MIMO antenna are contingent on the diversity gain.

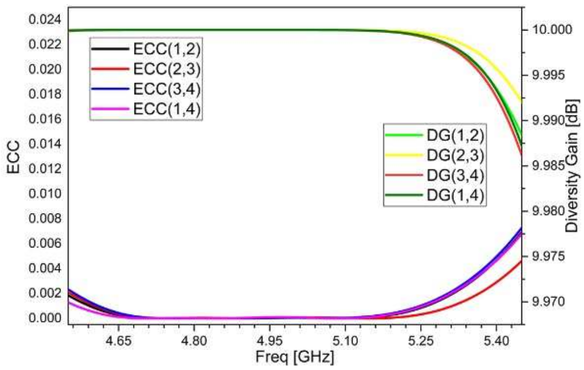

Figure 6. ECC and Diversity Gain of the MIMO antenna

Henceforth, a high value of DG (≈10 dB) indicate the acceptability of MIMO within the acceptable frequency band. Equation (2) displays the DG calculation using ECC value [3].

$$DG = 10\sqrt{(1-ECC)^2} \quad (2)$$

As shown in Figure 6, DG is found at 4.82GHz more significantly than 9.99999 dB (≈ 10 dB). The suggested antenna produced diversity performance values that are appropriate for the MIMO use.

5. Antenna Radiation Pattern

The 3-D radiation pattern of the proposed 4 port MIMO antenna (without DGS and with DGS) is shown in Fig 7. The loading of the decoupling structure in the ground plane also leads to a significant increase in gain, from 3.9 dB to 4.4 dB.

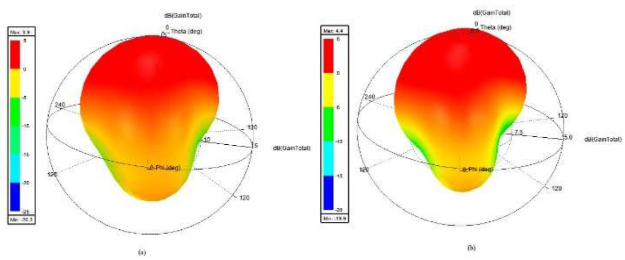

Figure 7. Radiation Pattern of the proposed MIMO at 4.82 GHz (a) Without DGS (b) with DGS

The proposed 2x2 MIMO antenna demonstrates superior characteristics in terms of antenna size (40x40x1.6 mm^3), achieving an overall gain of 4.4 dB and higher isolation of -60.19 dB through the use of a simple decoupling technique. A comparison between the proposed work and the existing recent research works is depicted in Table 2.

Table 2. Comparison Between Proposed Antenna and Existing Research

Ref. #	Overall Size of Antenna(mm^{3})	Freq. (GHz)	Decoupling/ Method	Gain (dBi)	Isolation (dB)	ECC	DG (dB)
[5]	60x60x1.524	5.25	DGS	--	-55	--	--
[7]	30x60x1.6	5.2	Parasitic element	3.8	-30	<0.5	>9.99
[10]	90x90x1.57	3.56, 5.28	Stub and Slot	4.2, 2.8	-22	<0.04	9.988
[11]	54.8x54.8x1.6	5.8	Polarization diversity and DGS	5.3	-32	<0.0001	9.998
[14]	56x48x1.6	2.32, 5.2	Hybrid Novel-Decoupling Structure	-1.21, -1.15	<-46, <-45	<0.001	>9.99
[15]	50x50x1.524	2.4	Modified ground	3.13	-22.59	--	--
Proposed Antenna	**40x40x1.6**	**4.82**	**Orthogonal Orientation and DGS**	**4.4**	**-60.19**	**<0.0001**	**~10**

6. Conclusion

A low profile, compact, 4-port 5G / WLAN MIMO antenna has been proposed which includes high isolations among the radiating elements. The gain and isolation of the presented antenna further enhanced by using DGS. The proposed MIMO antenna without DGS has an acceptable bandwidth of 150 MHz (4.72 to 4.85 GHz). Addition of the dumbbell-shaped decoupling units among the elements achieves an enhanced impedance bandwidth of 170 MHz (4.71 to 4.88 GHz) with maximum isolation of −60.19 dB at resonant condition. Moreover, the MIMO antenna has an acceptable value of ECC (<0.0001) as well as a satisfactory DG (9.99999 dB) characteristics. The proposed antenna's reflection characteristics, isolation, bandwidth and MIMO performance metric makes it a promising one for 5G communication.

7. References

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