# Wideband MIMO Antenna with Compact Decoupling Structure for 5G Wireless Communication Applications

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**Abstract**—This paper proposes a two element multiple-input multiple-output (MIMO) antenna with compact decoupling structure for 5G wireless communication applications. A compact decoupling structure was developed based on the elliptic curve, achieving isolation between the two antenna elements with a wideband response. The proposed concept is discussed and verified numerically and experimentally. The MIMO antenna system has demonstrated a wideband impedance matching with high isolation capability, while maintaining a good far-field and MIMO performance.

## 1. INTRODUCTION

Multiple-input multiple-output (MIMO) technology relies on multi-antenna elements at both transmitter and receiver that are sufficiently spaced apart in order to enrich wireless communication channels and thus result in better signal to noise ratio, increased channel capacity and data rate, among other parameters [1, 2]. It is well known that as spatial distance between multi-antenna elements is minimal, inherent electromagnetic interference or coupling arises due to either surface waves, space waves, diffracted waves, or even combinations, depending on the topology of the antenna system configuration [3]. As a result, significant electromagnetic coupling will deteriorate the performance of MIMO antenna systems in terms of impedance matching, gain, efficiency, and other MIMO performance indicators [4].

In order to maintain the integrity and performance of MIMO systems, it is instructive that mutual coupling should be kept to the minimum. Although no threshold level for mutual coupling has been set by industry, it has been a practice in academia to ensure the isolation between antenna elements below $-15\,\mathrm{dB}$, which translates into minimal electromagnetic interference between the antenna elements. This in turn is expected to enhance several MIMO metrics, including envelope correlation, diversity gain, among others [4].

The problem of electromagnetic coupling between radiating elements in MIMO systems could be tackled in one way by the integration of decoupling mechanisms within the antenna system. Various isolation techniques have been demonstrated in literature and can include any of the following, but not limited to: diversity techniques [5, 6], electromagnetic bandgap (EBG) structures [7], resonant slots within metallic ground layer, also termed as defected ground structures (DGS) [8], neutralization parasitic lines [9], and recently the deployment of artificial resonators [10].

In this research work, we propose a wideband highly decoupled MIMO antenna system for fifth-generation (5G) communication systems. The antenna array configuration consists of two radiating elements that are constructed from elliptically-shaped curves. Moreover, we propose a decoupling structure that is aligned with the finite ground structure to mitigate surface waves effect between the radiating elements. The decoupling structure is also constructed using a customized analytic curve of

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an ellipse shape. This kind of analytic curves can provide more flexibility in the design as well as achieve high isolation between coupled radiating elements. Numerical models are built using CST Microwave Studio, and results are discussed and compared with experimental results.

## 2. THE PROPOSED DECOUPLED ANTENNA SYSTEM

The decoupled antenna array structure is presented as shown in Fig. 1. The radiating elements are hosted on a very low-loss Rogers RO4003C laminate (a relative permittivity of 3.38 and $\tan \delta = 0.0027$). A small metallic ground layer of size $l_g \times w_g$ is deployed. Note that for the inter-element isolation computation, only a single radiating antenna was excited. In order to provide better impedance matching over a wideband frequency, a single antenna element is constructed from two orthogonal elliptically-shaped patches with different radii $r_x$ and $r_y$ along the $x$ and $y$ directions, respectively, and directly fed by a microstrip line. Among many analytic curve-based configurations, the proposed configuration is quite simple to design and realize. Moreover, it provides flexibility in the reconfiguration of the resonant frequency (see Fig. 1(a)).
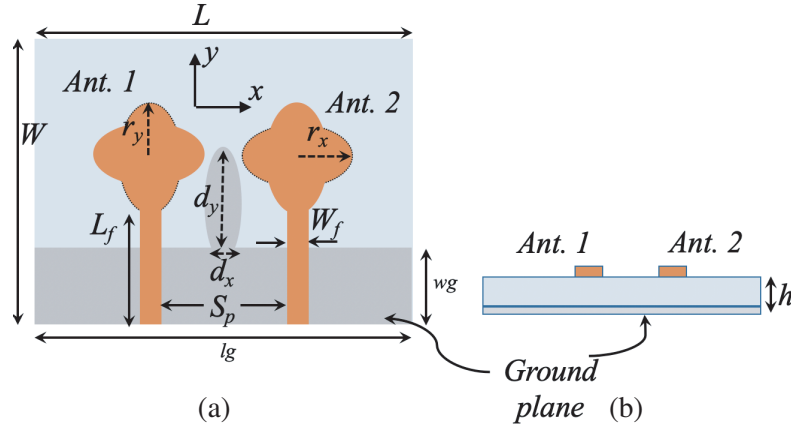


**Figure 1.** Schematic representations showing (a) top view; and (b) side view of the decoupled antenna system.

**Table 1.** Dimensions of the optimized wideband MIMO antenna structure.

| Parameter | Description | Value (mm) |
|:---:|:---:|:---:|
| $L$ | Length of MIMO antenna structure | 60 |
| $W$ | Width of MIMO antenna structure | 40 |
| $h$ | Thickness of substrate | 1.524 |
| $l_g$ | Length of finite metallic ground | 40 |
| $w_g$ | Width of finite metallic ground | 11 |
| $r_x$ | Radius of ellipse 1 | 5 |
| $r_y$ | Radius of ellipse 2 | 10 |
| $d_y$ | Length of decoupling ellipse | 19 |
| $d_x$ | Width of decoupling ellipse | 9 |
| $L_f$ | Length of microstrip feed line | 10.5 |
| $W_f$ | Width of microstrip feed line | 3 |
| $S_p$ | Spacing between radiating elements | 25 |

Through careful design process, the all elliptically-shaped MIMO antenna results in a wideband impedance matching and low coupling between the antenna elements, due to the smoothness in the curvature of the elliptically-shaped antenna and the decoupling unit. Table 1 lists all dimensions of the optimized wideband MIMO antenna structure, including the decoupling unit.

## 3. RESULTS AND DISCUSSIONS

### 3.1. Antenna Prototype

For validation purposes, prototypes are built, tested, and experimental results are presented, as illustrated in Fig. 2. A bottom view of the proposed decoupling structure can be seen in Fig. 2(b) and compared against a reference finite metallic ground layer, i.e., without a decoupling structure. Within the numerical models in CST Microwave Studio, the MIMO antenna system was excited using a 50 Ω edge-fed coaxial connector. All losses of the materials have also been taken into consideration, and all conductive layers were assigned as lossy copper.
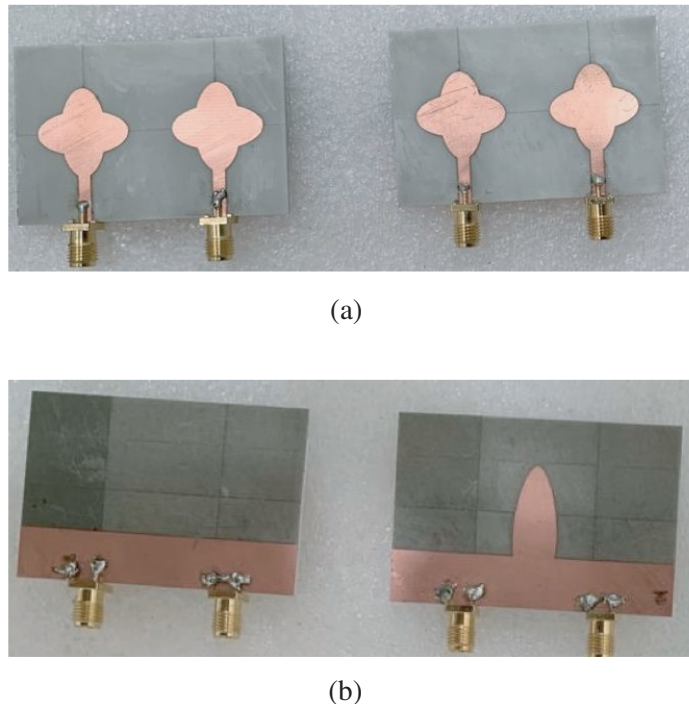


(a)



(b)

**Figure 2.** Images from the fabricated prototypes of the decoupled antenna system: (a) top view; and (b) bottom view.

### 3.2. Scattering Parameters Results

We first present the scattering parameters from the designed decoupled antenna structure. Fig. 3 shows the simulated reflection coefficient of the proposed coupled MIMO antenna structure which is validated by measured results. Good agreement was attained. As shown in Fig. 3(a), the impedance bandwidth obtained from measurements is in the range of 3.2–6.0 GHz, covering the 5G sub-6 GHz band. Fig. 3(b) depicts the mutual coupling, $S_{21}$, between the two antenna elements without the decoupling structure. Strong coupling around $-12$ dB between the antenna elements is illustrated without any decoupling structure.

The simulated and measured scattering parameters of the designed antenna system are shown in Fig. 4. The presence of the elliptical curve as a decoupling element in the ground layer has resulted in
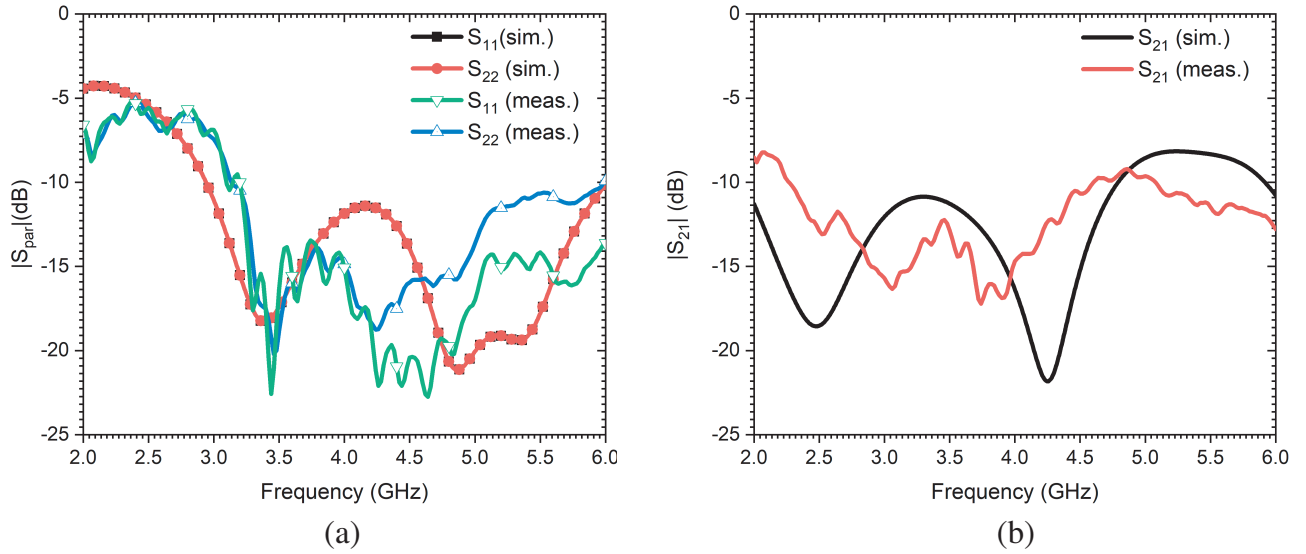
**Figure 3.** Simulation and experimental results of the coupled antenna structure: (a) $S_{11}$ magnitude; and (b) $S_{21}$ magnitude.
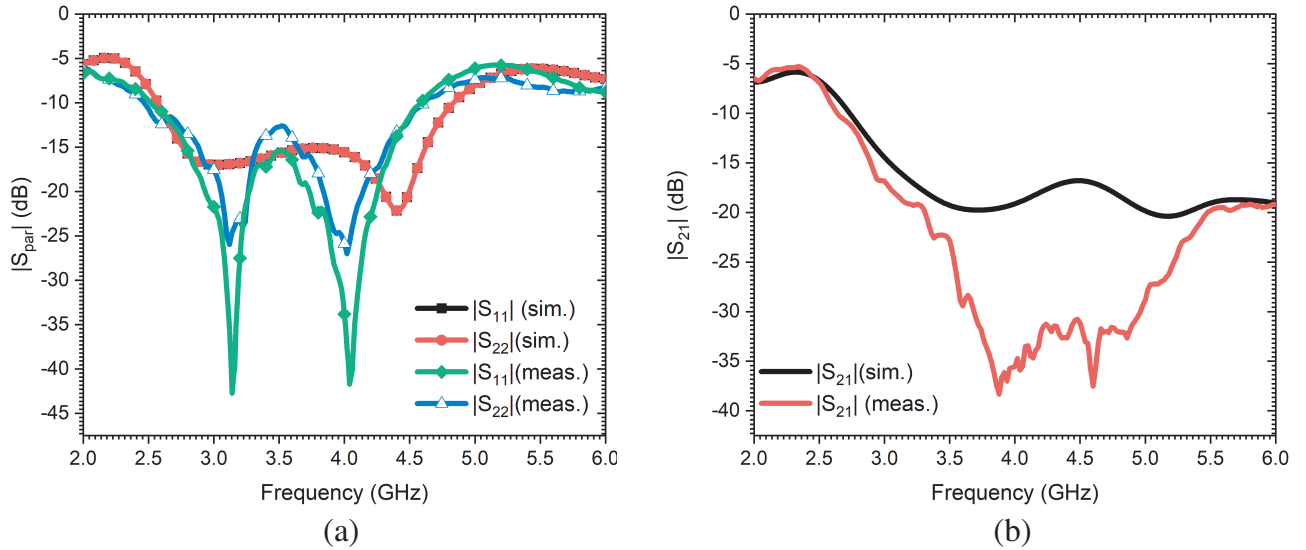


**Figure 4.** Simulation and experimental results of the decoupling antenna structure: (a) $S_{11}$ magnitude; and (b) $S_{21}$ magnitude.

slightly lowering the impedance bandwidth of the antenna system but still maintaining wide bandwidth including the 3.5 GHz frequency band. Fig. 4(b) shows that the two antennas are highly decoupled, where the isolation of more than 15 dB was obtained between the two antenna elements as compared against the reference case, i.e., without decoupling structure.

The surface current distribution for the proposed decoupled antenna system is presented next at 3.5 GHz. As illustrated in Figs. 5(a)–(b), significant surface current coupling to the receiving antenna (right-side antenna in Fig. 5(b)) is observed for the case without the decoupling structure, while the decoupling unit in Fig. 5(a) has resulted in mitigating the coupling effect between the antenna elements, as evidence from minimal current flow within the second antenna element, i.e., right-side antenna unit.
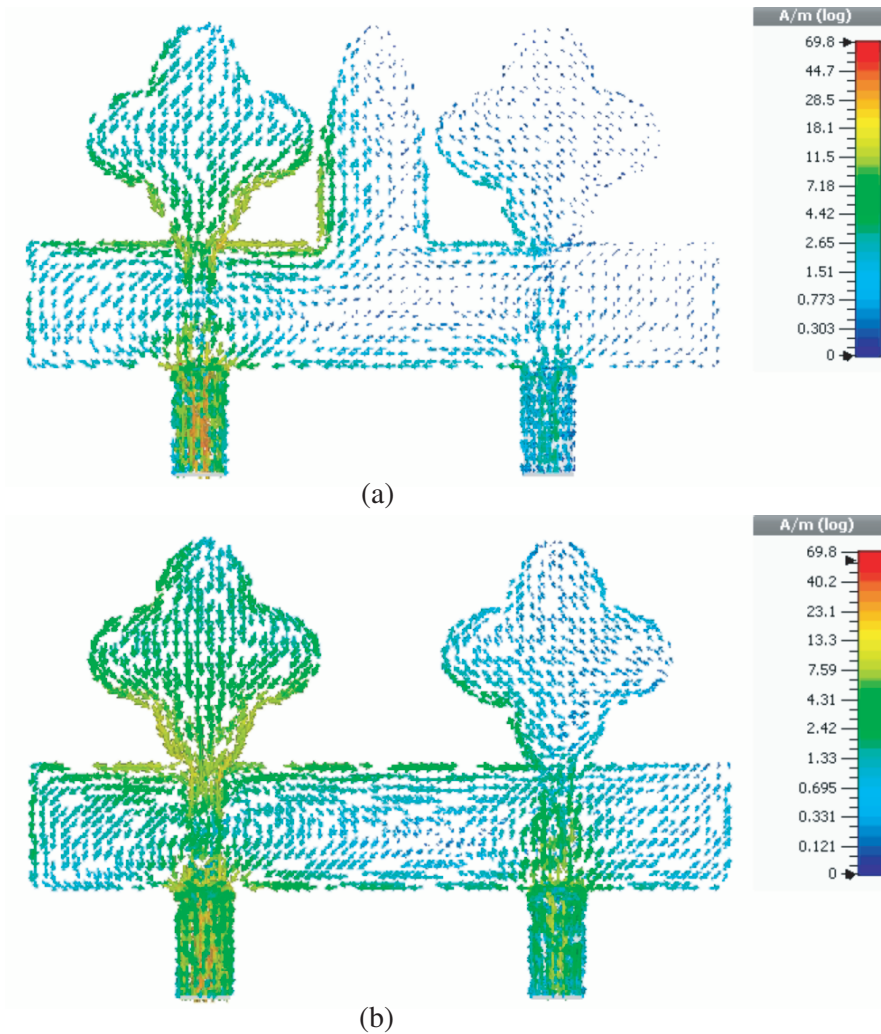
**Figure 5.** Snapshots of surface current distribution at 3.5 GHz for the MIMO antenna: (a) with and (b) without the decoupling structure.

### 3.3. Far-Field Properties

Next, the radiation properties of the decoupled antenna system are studied and discussed. Fig. 6 presents the simulated 3D radiation patterns of the proposed MIMO antenna system at 3.5 GHz. The gain pattern plots in Fig. 6 show that the antenna has its main radiation slightly tilted from the ($\theta = 0°$) direction with a little backlobe radiation, due to the finite size of the metallic reflector. From the 3D radiation pattern, it is visible that pattern diversity is realizable when one port is excited, while the port of the other antenna is terminated by 50 Ω impedance.

The total efficiency and peak gain of the decoupled MIMO antenna have been calculated numerically with a frequency sweep as seen in Fig. 7. In particular, the peak gains of the MIMO antenna system at 3.5 GHz with and without the decoupling structure are 3.86 dBi and 3.7 dBi, respectively, while the total efficiencies are 94% and 89% for the cases of the antenna structure with and without the decoupling elliptical curve element, respectively.

### 3.4. MIMO Performance

In this part, we focus on evaluating several MIMO performance metrics to ensure that the proposed antenna configuration is suitable for MIMO applications. The first important parameter is the envelope
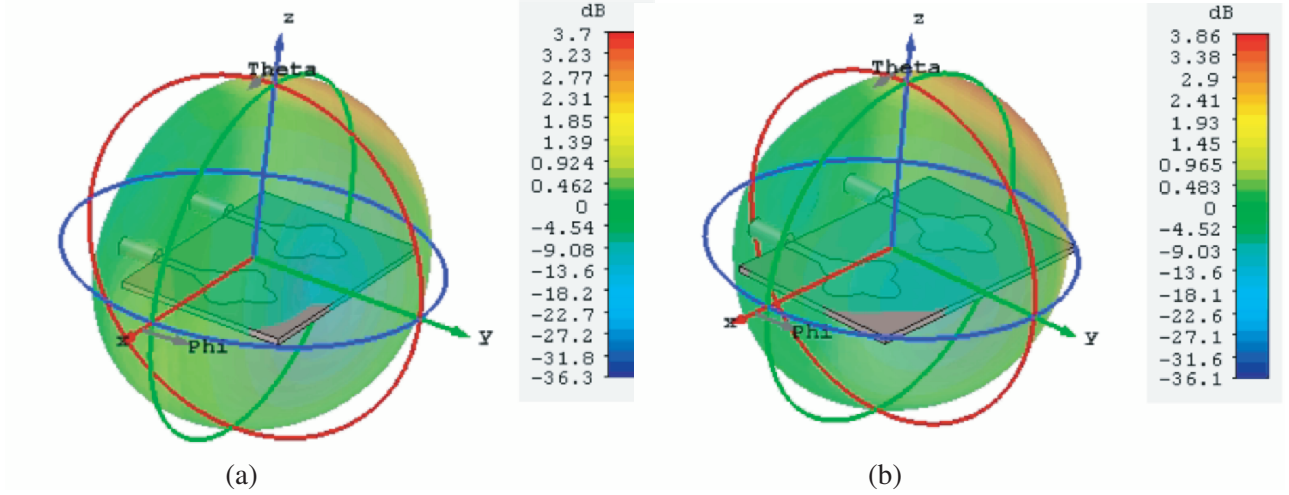
(a)                                                                 (b)

**Figure 6.** Simulated 3D radiation patterns for the proposed MIMO antenna at 3.5 GHz: (a) without and (b) with the decoupling structure.
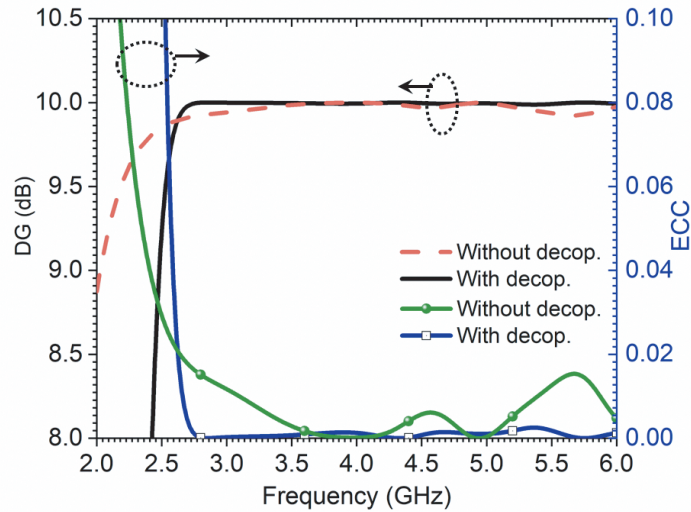


**Figure 7.** Simulation results showing peak gain and total efficiency of the proposed MIMO antenna with and without the decoupling structure.

correlation coefficient ($ECC$), which can be computed from the scattering parameters using the following relation [11]

$$ECC = \frac{|S_{11}^* S_{12} + S_{21}^* S_{22}|^2}{[1 - (|S_{11}|^2 + |S_{21}|^2)][1 - (|S_{22}|^2 + |S_{12}|^2)]}. \tag{1}$$

It is essential that this ECC parameter is maintained as low as possible for the overall antenna system in order to be suitable for MIMO applications. Fig. 8 shows the numerically computed envelope correlation coefficient (ECC) from the $S$-parameters of the proposed MIMO antenna system with and without the isolation unit. As can be seen, the proposed decoupling structure results in better ECC for the MIMO antenna structure than the case without isolation mechanism. The ECC for the MIMO antenna without the decoupling unit at 3.5 GHz is computed as 0.003, while that for the case of MIMO antenna with decoupling structure is below 0.001, even maintained over the 3 GHz–6 GHz.

    Another important MIMO performance factor is the diversity gain (DG), which is studied next. The diversity gain of the proposed MIMO antenna with the decoupling unit is calculated as a post
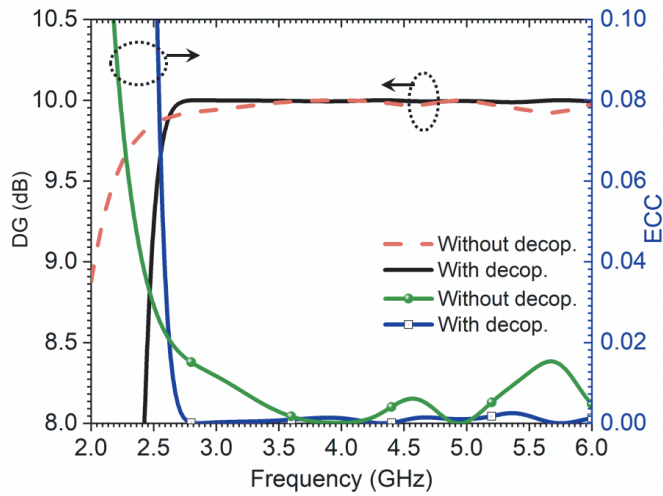
**Figure 8.** Numerical results showing ECC and DG of the proposed MIMO antenna with and without the decoupling structure.

processing parameter using CST Microwave Studio, as presented in Fig. 8. The DG metric can be computed by:

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

As shown in Fig. 8, the calculated DG of the proposed MIMO antenna with the decoupling structure is maintained at almost 9.5 dB as compared against the reference case, which is slightly below the DG of the MIMO antenna with the decoupling unit.

Table 2 summarizes the performance of recent MIMO antenna structures in literature and compared with the proposed structure. As can be seen, the proposed wideband MIMO antenna structure has

**Table 2.** Comparison of recent MIMO antenna structures with the proposed wideband MIMO antenna design.

| Reference | Decoupling tech. | Impedance BW | Isolation (dB) | ECC | Gain (dB) | % Efficiency | DG (dB) |
|---|---|---|---|---|---|---|---|
| [9] | Neutralization line | 1.91–2.18 GHz | 22 | - | 2.1 | 90 | - |
| [10] | Slotted-CSRRs | 4.8–5 GHz | 10 | - | 5.3 | 70 | - |
| [12] | Multilayer + EBG | 3–3.18 GHz | 15 | - | - | - | - |
| [13] | EBG superstrate | 5.7–5.8 GHz | 11 | - | - | - | - |
| [14] | Meander Lines | 4.7–5.2 GHz | 10 | - | - | - | - |
| [15] | resistive loading | 3–9 GHz | 15 | < 0.015 | 1–5 | 90 | 9.96 |
| [16] | Complementary resonators | 5.58–5.68 GHz | 22 | < 0.02 | 5.1 | > 40 | - |
| This work | Elliptical resonator | 3.2–6 GHz | > 15 | 0.003 | 3.86 | 94 | 9.5 |

satisfactory performance compared to the presented list as well as to other published structures. The moderate impedance bandwidth, good isolation improvement, low ECC, and quite stable DG make the proposed candidate well suited for many 5G wireless applications.

## 4. CONCLUSION

A wideband printed MIMO antenna system with high isolation capability has been proposed for 5G wireless communication applications. An all elliptically-shaped antenna structure with a compact decoupling unit was realized. Numerical and experimental results agree quite well.

The proposed MIMO antenna system provides wideband impedance matching with high isolation between its elements. The simulated gain and total efficiency of the decoupled antenna system are 3.86 dBi and 94% at 3.5 GHz, respectively. Moreover, good performance is achieved in terms of MIMO metrics, which makes it well suited for 5G MIMO applications.

## ACKNOWLEDGMENT

## REFERENCES

1. Foschini, G. and M. Gans, "On limits of wireless communications in a fading environment when using multiple antennas," *Wireless Personal Commun.*, Vol. 6, No. 3, 311–335, March 1998.
2. Wallace, J., M. Jensen, A. Swindlehurst, and B. Jeffs, "Experimental characterization of the MIMO wireless channel: Data acquisition and analysis," *IEEE Transactions Wireless Commun.*, Vol. 2, No. 2, 335–343, March 2003.
3. Pozar, D. M., "Considerations for millimeter wave printed antennas," *IEEE Transactions on Antennas and Propagation*, Vol. 31, No. 5, 740–747, September 1983.
4. Kildal, P.-S. and K. Rosengren, "Correlation and capacity of MIMO systems and mutual coupling, radiation efficiency and diversity gain of their antennas: Simulations and measurements in a reverberation chamber," *IEEE Communications Magazine*, Vol. 42, No. 12, 104–112, December 2004.
5. Zhang, S., B. K. Lau, A. Sunesson, and S. He, "Closely-packed UWB MIMO/diversity antenna with different patterns and polarizations for USB dongle applications," *IEEE Transactions on Antennas and Propagation*, Vol. 60, No. 9, 4372–4380, September 2012.
6. Pllo, M., et al., "A broadband pattern diversity annular slot antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 60, No. 3, 1596–1600, March 2012.
7. Yang, F. and Y. Rahmat-Samii, "Microstrip antennas integrated with Electromagnetic Band-Gap (EBG) structures: A low mutual coupling design for array applications," *IEEE Transactions on Antennas and Propagation*, Vol. 51, No. 10, 2936–2946, October 2003.
8. Zhu, F.-G., J.-D. Xu, and Q. Xu, "Reduction of mutual coupling between closely packed antenna elements using defected ground structure," *Electronics Letters*, Vol. 45, No. 12, 601–602, 2009.
9. Diallo, A., et al., "Study and reduction of the mutual coupling between two mobile phone PIFAs operating in the DCS1800 and UMTS bands," *IEEE Transactions on Antennas and Propagation*, Vol. 54, No. 11, 3063–3073, November 2006.
10. Bait-Suwailam, M. M., O. Siddiqui, and O. Ramahi, "Mutual coupling reduction between microstrip patch antennas using slotted-complementary split-ring resonators," *IEEE Antennas and Wireless Propagation Letters*, Vol. 9, 876–878, 2010.
11. Blanch, S., J. Romeu, and I. Corbella, "Exact representation of antenna system diversity performance from input parameter description," *Electronics Letters*, Vol. 39, No. 9, 705–707, May 2003.

12.  Rajo-Iglesias, E., Ó. Quevedo-Teruel, and L. Inclan-Sanchez, "Mutual coupling reduction in patch antenna arrays by using a planar EBG structure and a multilayer dielectric substrate," *IEEE Transactions on Antennas and Propagation*, Vol. 56, No. 6, 1648–1655, June 2008.

13.  Farahani, H. S., M. Veysi, M. Kamyab, and A. Tadjalli, "Mutual coupling reduction in patch antenna arrays using a UC-EBG superstrate," *IEEE Antennas and Wireless Propagation Letters*, Vol. 9, 57–59, 2010.

14.  Alsath, M. G. N., M. Kanagasabai, and B. Balasubramanian, "Implementation of slotted meander-line resonators for isolation enhancement in microstrip patch antenna arrays," *IEEE Antennas and Wireless Propagation Letters*, Vol. 12, 15–18, 2013.

15.  Park, J., M. Rahman, and H. N. Chen, "Isolation enhancement of wide-band MIMO array antennas utilizing resistive loading," *IEEE Access*, Vol. 7, 81020–81026, 2019.

16.  Mohamadzade, B., A. Lalbakhsh, R. B. V. B. Simorangkir, A. Rezaee, and R. M. Hashmi, "Mutual coupling reduction in microstrip array antenna by employing cut side patches and EBG structures," *Progress In Electromagnetics Research M*, Vol. 89, 179–187, 2020.