International Journal of Microwave and Wireless Technologies

cambridge.org/mrf

Design and analysis of 4 × 4 MIMO antenna with DGS for WLAN applications

K. Malaisamy[1,2], M. Santhi[1,2] and S. Robinson[1,3]

[1]Department of Electronics and Communication Engineering, TamilNadu, India; [2]Saranathan college of Engineering, Trichy, Tamil Nadu 620012, India and [3]Mount Zion college of Engineering and Technology, Pudukottai, Tamil Nadu 622507, India

Research Paper

Cite this article: Malaisamy K, Santhi M, Robinson S (2021). Design and analysis of 4 × 4 MIMO antenna with DGS for WLAN applications. *International Journal of Microwave and Wireless Technologies* **13**, 979–985. https://doi.org/10.1017/S1759078720001658

Received: 4 August 2019
Revised: 25 November 2020
Accepted: 26 November 2020
First published online: 22 December 2020

Key words:
Antenna; defected ground structure; FR4; MIMO; WLAN

Author for correspondence:
K. Malaisamy,
E-mail: malaisamyme@gmail.com

Abstract

In this paper, a low profile 4 × 4 multiple input and multiple output (MIMO) antenna is proposed and designed for wireless local area network (WLAN) application using a square split-ring resonator. Initially, a single square-patch antenna is designed with square-shaped split-ring slot. Subsequently, the two-element MIMO antenna is designed and it is extended to four-element MIMO antenna. Finally, the defected ground structure (DGS) is implemented in order to enhance antenna performance. The antenna elements are placed opposite to each other. The mutual coupling between the antennas elements is reduced by DGS. The proposed single, two and four-element antennas operate at 5.8 GHz for WLAN. The overall performance is measured in terms of S parameter, radiation pattern, and envelope correlation coefficient. The simulated results are verified through measurements. The simulated and measured results demonstrate that the proposed 4 × 4 MIMO antenna is the most suitable for WLAN applications.

Introduction

Wireless local area network (WLAN) is an important technology to provide an inherent property such as high-speed transmission rate, high security, low cost, low power consumption, and high signal to noise ratio. The performance of the antenna is achieved by multiple input and multiple output (MIMO) antenna [1]. In a MIMO system, more than one antenna is used as transmitter and receiver. It is used to improve the communication quality and increase the channel capacity.

Typically, the MIMO antenna faces two major problems namely the size of the antenna and mutual coupling between the antenna elements. One is to minimize the size of MIMO antenna. In order to reduce the size of the antenna, they are placed close to each other. Owing to this arrangement, it produces mutual coupling. The mutual coupling is reduced by various types of isolation techniques, namely, antenna placement and orientation [2], decouple network [3], inclusion of parasitic element [4], defected ground structure (DGS) [5], neutralization line [6], metamaterial structure [7, 8] etc.

Abdulla *et al.* proposed two-element metamaterial MIMO antennas. It consists of two zeroth-order resonator to reduce the size of an antenna and DGS filter is introduced for avoiding mutual coupling [9]. Thummalaru *et al.* have projected a two-monopole antenna with negative metamaterial as a decoupling network [10]. A metamaterial array is used as a substrate coated with polymer industrial adhesive [11]. Jusoh *et al.* designed two-elements MIMO antennas where each element consists of seven circles surrounded by a center circle. A partial ground plane is employed to improve the isolation [12]. Merihpalankonden *et al.* developed two dipole MIMO antennas. Each dipole antenna is connected with a six-unit cell. A truncated slot is introduced on a truncated ground plane to improve the isolation [13]. Nordin *et al.* designed a three left-handed metamaterial unit cell. Each unit cell consists of split-ring slot with capacitive loaded. A trident feed and slotted ground are employed to match the antenna and input port [14]. The two monopole antenna is designed and a quarter wavelength slot and open-ended slot are used to improve the isolation [15].

Chou *et al.* devised a three-loop antenna with different antenna arrangement. The middle antenna was placed at a horizontal position. It is orthogonal to other antenna elements for better isolation. A T-shaped slot and ground strip are used to enhance antenna performance [6]. Mallahzadesh *et al.* reported E shape two and four-element MIMO antenna where the isolation is enhanced by invasive weed optimization algorithm [16]. Yu *et al.* proposed matching network derived using power allocation rule. The genetic algorithm was utilized to optimize the performance [17]. The T shaped parasitic element is implemented for the isolation [18]. Kim *et al.* introduced the radiating elements and one-dimensional electromagnetic bandgap reflectors to reduce the mutual coupling [19]. Krairiksh *et al.* designed a two-probe circular ring. The isolation between the two probes is enhanced by the insertion of an inductor coil between the probes [20]. In addition, there are several four-element MIMO antennae designed and developed for WLAN, worldwide interoperability for microwave access (WiMax)

CAMBRIDGE UNIVERSITY PRESS

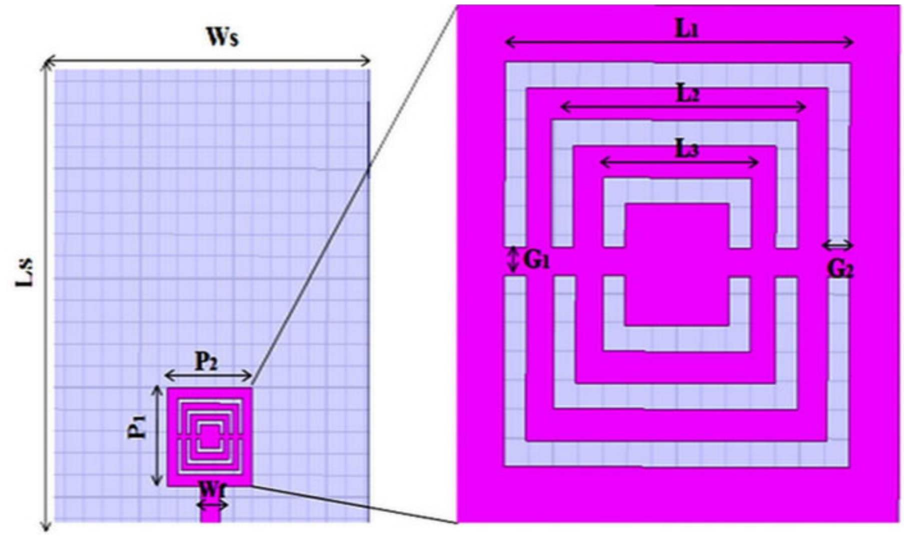

Fig. 1. Schematic structure of unit element square patch with split-ring slot antenna.

Table 1. Structural parameters of a single element (mm) antenna.

Parameter	Value (mm)
Patch length (P_1)	9
Patch width (P_2)	9
Substrate length (L_s)	42.837
Substrate width (W_s)	34.485
Feed width (W_f)	2.05
Gap between two slots (G_1)	0.48
Width of slots (G_2)	0.45

applications, ultra wide band (UWB) applications, industrial scientific and medical (ISM) band, universal mobile telecommunications system (UMTS), long-term evolution (LTE) and 4G/5 G smartphone applications. It is designed using Slot, dielectric resonator antenna (DRA), complementary split ring resonator (CSRR), DGS, and inverted F/L antenna [21–36].

In the literature, several MIMO antennas, with various decoupling structures are reported for WLAN applications where the metamaterial and DGS are mostly used for MIMO applications to minimize the mutual coupling. Further, it is also investigated that isolation is needed to be enhanced and the size of the patch is large. In order to mitigate the above-mentioned issues, the square patch with a square-shaped split-ring slot is introduced to develop 4 × 4 MIMO antenna.

In this paper, a MIMO antenna (single MIMO antenna, 2 × 2 MIMO antenna without DGS and 4 × 4 MIMO antenna without and with DGS) is proposed and designed and its functional parameters namely, return loss, VSWR, resonant frequency, isolation, radiation pattern, and envelope correlation coefficient (ECC) are investigated. DGS is introduced in 4 × 4 MIMO antenna in order to enhance the performance of the antenna. Finally, the simulated return loss is compared with that of a fabricated antenna.

This paper is arranged in the following way: Antenna geometry and design illustrates the design of single MIMO antenna, 2 × 2 MIMO antenna without DGS and 4 × 4 MIMO antenna without and with DGS and its return loss performance of simulated and measured. MIMO antenna results and discussions illustrates the simulation results of 4 × 4 MIMO antenna namely, isolation, radiation pattern and ECC. Conclusion concludes the paper.

Antenna geometry and design

The proposed antenna is designed as a low-cost FR4 substrate with relative permittivity of 4.4. The resonant frequency is calculated as per Ref. [11]. The width and length of the patch are 5.4 mm and 5.4 mm, respectively. The thickness of the substrate is 0.8 mm and loss tangent is 0.02. The patch height is 1.1 mm from the ground plane. According to the calculation, the single, double element, and four-element MIMO antenna are designed. The substrate has a dimension of 34.485 mm width and 42.837 mm length. The patch size is 9 mm × 9 mm.

Single element antenna

The unit element of the proposed antenna is shown in Fig. 1. The unit element is used to design a proposed MIMO antenna. It is operated at 5.8 GHz. The antenna is fed by 50 Ω microstrip line. The structural parameters and the values of the proposed antenna are listed in Table 1.

The return loss $|S_{11}|$ of the proposed antenna is shown in Fig. 2. The square-shaped split-ring slot is introduced on the patch to reduce the electrical length of the antenna. The slot width is 0.45 mm. The size of the antenna is less than the operating wavelength, using the square-shaped split-ring resonator. The split-ring resonator is designed according to the radiation on the patch. The return loss of the proposed antenna is −27.2366 dB at 5.8 GHz.

The return loss comparison of simulated and measured single patch antenna is shown in Fig. 2. The return loss is −25 dB at 5.9 GHz. The change in return loss and the resonant frequency is due to the incorporation of SubMiniature version A (SMA) connector in the fabricated antenna.

Double element MIMO antenna

The design of a double element MIMO antenna is shown in Fig. 3. The antenna is designed as two-unit element antennas which are placed opposite to each other. However, the other structural parameters are similar to a single element antenna.

https://doi.org/10.1017/S1759078720001658 Published online by Cambridge University Press

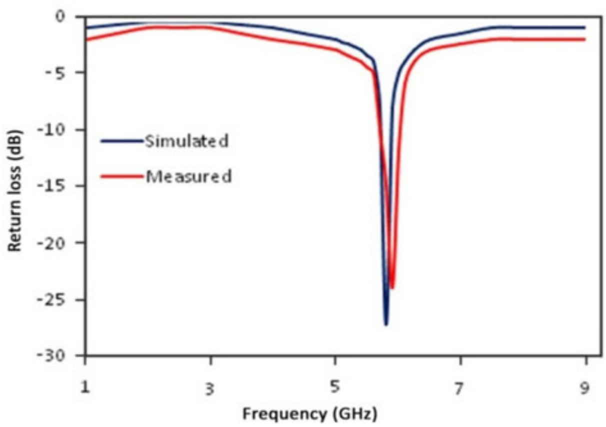

Fig. 2. Return loss response of the unit element of square patch with split-ring slot antenna.

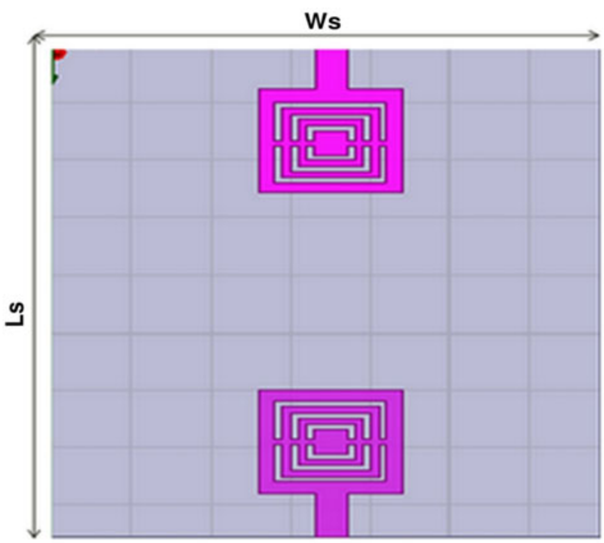

Fig. 3. Schematic structure of double elements MIMO antenna.

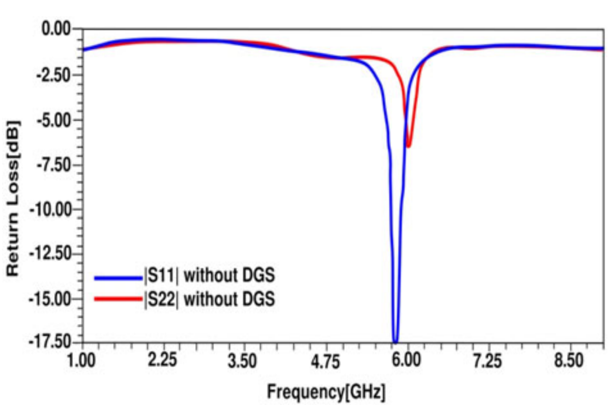

Fig. 4. Simulated return loss response of a double element MIMO antenna.

The return loss of two elements MIMO is shown in Fig. 4. When port 1 is excited, port 2 is matched with the strong electromagnetic energy coupling between the two elements. As a result, the return loss of port 1 is degraded. As there is no isolation technique used between the antenna elements, it introduces mutual coupling. Owing to the mutual coupling between the ports, the return loss is reduced at port 1 which is −17.50 dB at 5.8 GHz and port 2 resonates −6 dB at 6 GHz. However, the return loss of the single element antenna is −27.2366 dB at 5.8 GHz.

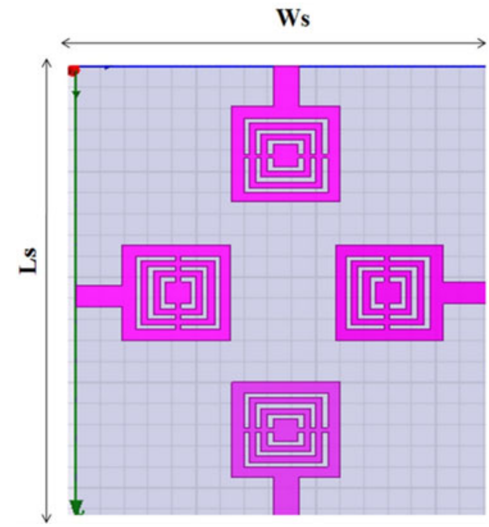

Fig. 5. Schematic structure of four-element MIMO antenna without DGS.

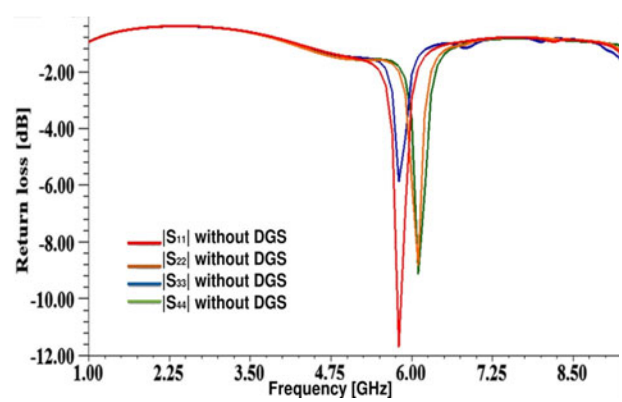

Fig. 6. Simulated return loss response of four-element MIMO antenna without DGS.

Four-element MIMO antenna

The proposed four-element MIMO antenna is shown in Fig. 5. The antenna is designed as a four-unit element antenna which is placed at the center of each side. The length and width of the patch remain the same as a single element MIMO antenna.

The simulated return loss response of four-element MIMO antenna is shown in Fig. 6. There is no isolation technique used between the antenna elements to minimize the mutual coupling. Hence, the return loss of port 1 resonates −11.69 dB at 5.8 GHz, port 2 resonates −8.8 dB at 6.1 GHz, port 3 resonates −5.8 dB at 5.8 GHz and port 4 resonates −9.12 dB at 6.1 GHz. There are several types of isolation techniques reported for antenna placement and orientation [1], algorithms [5], parasitic elements [2], DGSs, neutralization lines [6], and metamaterial structures [7]. Here, the DGS is introduced to enhance antenna performance.

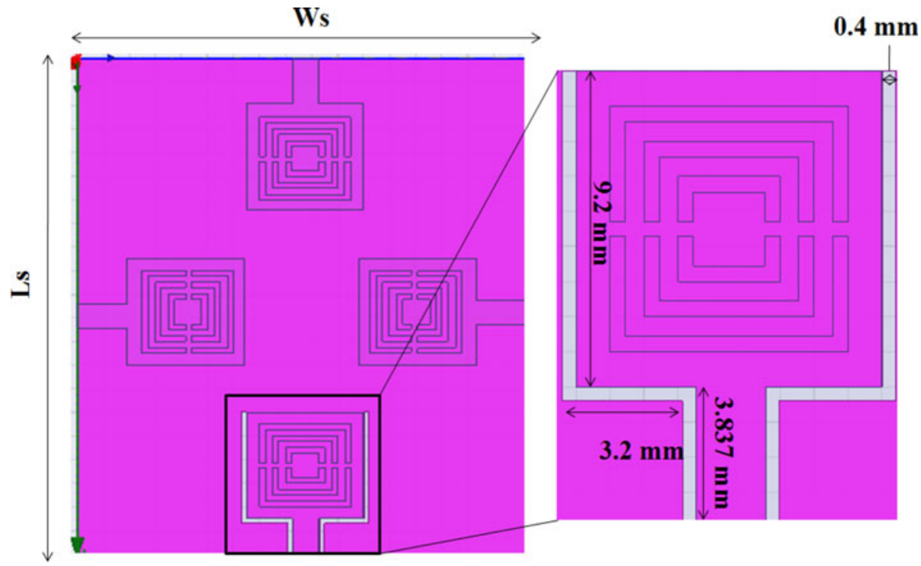

Fig. 7. Schematic structure of four-element MIMO antenna with DGS.

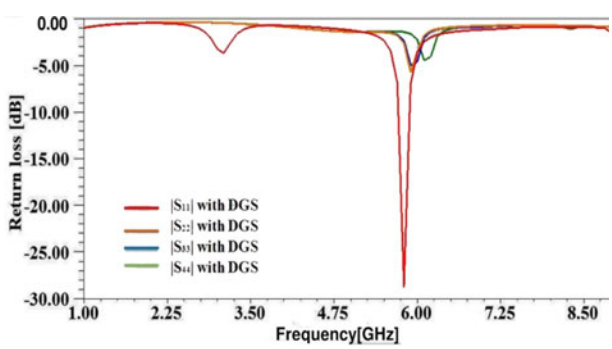

Fig. 8. Simulated return loss response of four-element MIMO antenna with DGS.

In between the antenna elements, mutual coupling is introduced which reduces the performance of the antenna. For avoiding the mutual coupling, the two meandered line-shaped slots like DGS is introduced on the ground plane. The two meandered line-shaped slot is placed on the ground plane in between the first antenna element because the radiation of this antenna element affects the nearby antenna element. The thickness of the slot is 0.4 mm. The return loss is improved at port 1 by this structure. The four-element MIMO antenna with the size of the DGS is shown in Fig. 7.

The return loss of four-element MIMO with DGS is shown in Fig. 8. Two meandered line slots introduced on the ground plane are used to enhance the return loss performance. The return loss of port 1 resonates −28.75 dB at 5.8 GHz, port 2 resonates −5.77 dB at 5.9 GHz, port 3 resonates −7 dB at 6.1 GHz, port 4 resonates −4 dB at 5.9 GHz. The return loss is improved by incorporating the DGS in between the antenna elements. DGS suppresses the unwanted wave in the ground plane. As a result, the return loss is enhanced from −11.69 dB to −28.75 dB.

The impedance bandwidth is just the normal bandwidth of the antenna. Eventually, it is defined as the range of frequencies over which the return loss is acceptable. The 6 dB impedance bandwidth of the proposed antenna without and with DGS is about 0.10 GHz and 0.35 GHz, respectively. The impedance bandwidth of the proposed antenna without DGS is 0.10 GHz which spans from 5.8 GHz to 5.9 GHz. The 0.35 GHz impedance bandwidth arrives with DGS over the ranging from 5.6 GHz to 5.95 GHz. The impedance bandwidth of the proposed antenna meets the requirements for 802.11a/n/ac.

The antenna efficiency is calculated. The antenna efficiency of the proposed 4 × 4 MIMO antenna with/without DGS is reported in the revised paper. The antenna efficiency of an antenna with/without DGS is 87.5% and 83%, respectively. The fabricated four-element patch antenna's front and back view are shown in Fig. 9. The overall size of an antenna is very small (about 42.837 mm × 34.485 mm × 0.8 mm.).

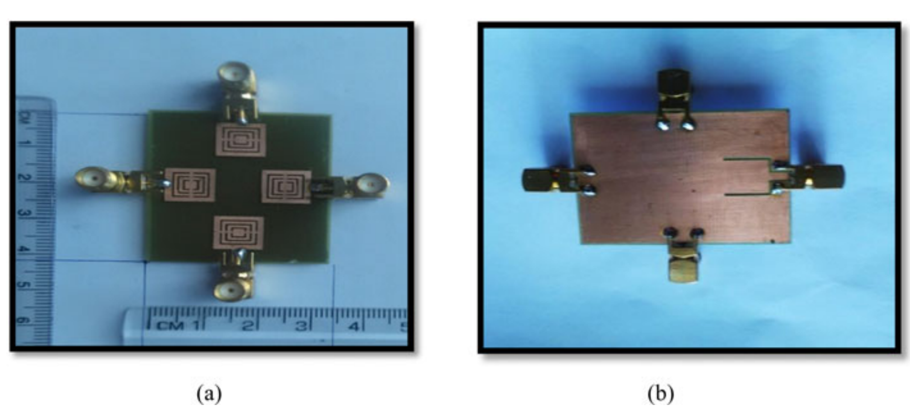

Fig. 9. Fabricated four-element MIMO antenna with DGS (a) front view and (b) back view.

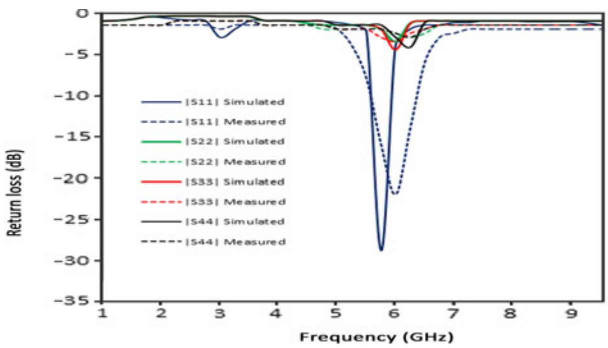

Fig. 10. Return loss response of dual-element MIMO antenna with DGS.

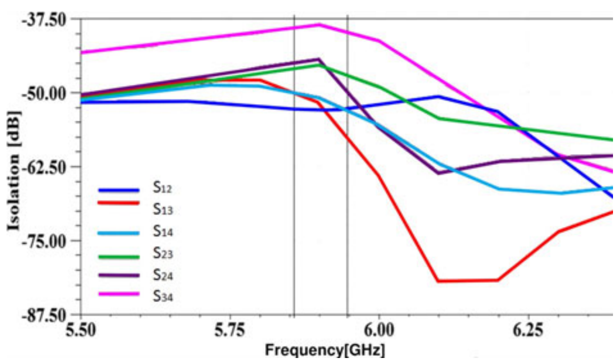

Fig. 11. Simulated isolation response of four-element MIMO antenna with DGS.

The return loss comparison of simulated and measured four-element MIMO antenna is shown in Fig. 10. The measured results are slightly varied from the simulated result. During the simulation, the SMA connector is not included. Owing to the insertion loss the resonant frequency is shifted to 6.1 GHz with the return loss of −22 dB.

MIMO antenna results and discussions

The 4 × 4 MIMO antennas is designed and the isolation, radiation pattern, and ECC are simulated and presented here.

Isolation

Isolation is used to find out how much power is coupled between the adjacent antenna elements by using the structure of antenna elements. Figure 11 shows the isolation curve of proposed four-element MIMO antenna. The isolation is calculated in between port 1 and 2, port 1 and 3, port 1 and 4, port 2 and 3, port 2 and 4, port 3 and 4.

Radiation characteristics

The simulated radiation patterns in *H*- and *E*-planes are presented in Fig. 12. The simulated radiation pattern of the proposed antenna is at the frequency of 5.8 GHz. The representation of the 2D radiation pattern of the simulated result is unidirectional in *E* plane and bidirectional in *H* plane.

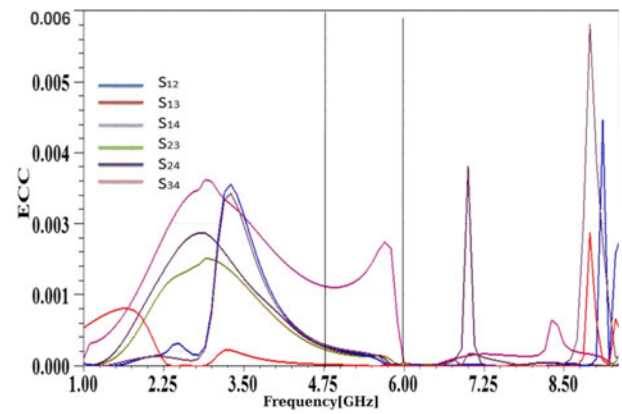

Fig. 12. Radiation patterns of four-element MIMO antenna with DGS antenna.

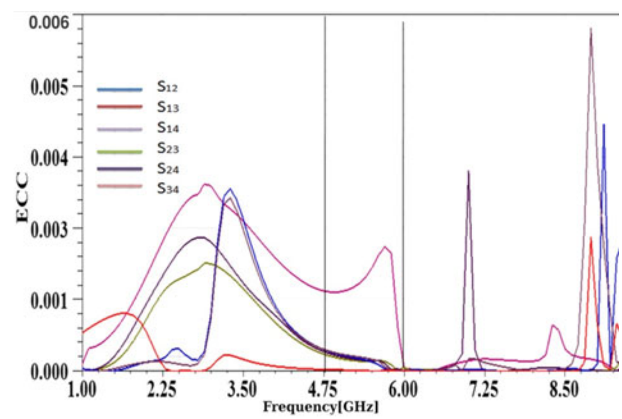

Fig. 13. Simulated ECC response of four-element MIMO antenna with DGS.

Envelope correlation coefficient

The capacity of the proposed MIMO antenna is analyzed by ECC. The MIMO antenna is necessary to obtain a low ECC. ECC computes the correlation between the branch signals received by the different elements, and lower ECC signifies higher pattern diversity [10]. By assuming the proposed antenna as a lossless antenna in an isotropic scattering environment, the ECC between *i* and *j*, is calculated using the following equation. The ECC of two elements with DGS is shown in Fig. 13:

$$\rho_{eij} = \frac{|s_{ii}^* s_{ij} + s_{ji}^* s_{jj}|}{(1 - |s_{ii}|^2 - |s_{ij}|^2)(1 - |s_{jj}|^2 - |s_{ji}|^2)}$$

The ECC is calculated in between port 1 and 2, port 1 and 3, port 1 and 4, port 2 and 3, port 2 and 4, port 3 and 4. The ECC of four elements with DGS structure is <0.0001. The ECC is improved by the DGS. The values are well below the acceptable limit of 0.5 [6]. From the above analysis, it can be seen that the designed antenna has the smallest size and has low mutual coupling between the antennas. Hence, the proposed antenna is highly desirable for WLAN applications.

Conclusion

In this paper, four-element MIMO antennas, with DGS are proposed and designed. The functional characteristics of the

https://doi.org/10.1017/S1759078720001658 Published online by Cambridge University Press

proposed antenna, namely return loss, isolation, radiation pattern, and ECC are investigated. The return loss of the four-element MIMO antenna is −28.75 dB at 5.8 GHz. However, the return loss is reduced to −22 dB after the fabrication due to SMA connector. The overall size of the antenna is 42.837 mm × 34.485 mm × 0.8 mm. The radiating patch-size is 9 mm × 9 mm. The mutual couplings between the antennas elements are minimized through DGS. The ECC is <0.0001. Hence, the proposed antenna meets the requirements for WLAN-applications.

References

1. **Jensen M and Wallace JW** (2004) A review of antennas and propagation for MIMO wireless communication. *IEEE Transaction on Antennas and Propagation* **52**, 2810–2824.
2. **Sharma Y, Sarkar D, Saurav K and Srivastava KV** (2016) Three element MIMO antenna system with pattern and polarization diversity for WLAN application. *IEEE Antennas and Wireless Propagation Letters* **16**, 1163–1166.
3. **Goldsmith A, Jafar SA, Jindal N and Vishwanath S** (2003) Capacity limits of MIMO channels. *IEEE Journal on Selected Areas in Communications* **21**, 684–702.
4. **Khan MS, Shafique MF, Naqvi A, Capobianco AD, Ijaz B and Braaten BD** (2015) A miniaturized dual band MIMO antenna for WLAN applications. *IEEE Antennas and Wireless Propagation Letters* **14**, 958–961.
5. **Anitha R, Sarin VP, Mohanan P and Vasudevan K** (2014) Enhanced isolation with defected ground structure in MIMO antenna. *Electronics letter* **50**, 1784–1786.
6. **Chou HT, Cheng HC, Hsu HT and Kuo LR** (2008) Investigation of isolation improvement techniques for multiple input multiple output (MIMO) WLAN portable terminal applications. *Progress In Electromagnetic Research B* **85**, 349–366.
7. **Zhu J and Eleftheriades GV** (2009) A compact transmission line metamaterial antenna with extended bandwidth. *IEEE Antennas and Wireless Propagation Letters* **8**, 295–298.
8. **Ziolkowski W and Erentok A** (2006) Metamaterial based efficient electrically small antennas. *IEEE Antennas and Wireless Propagation Letters* **54**, 2113–2129.
9. **Abdulla MA and Ibrahim AA** (2013) Compact and closely spaced metamaterial MIMO antenna with high isolation for wireless applications. *IEEE Antennas and Wireless Propagation Letters* **12**, 1452–1455.
10. **Thummaluru SR and Chaudhary RK** (2017) Mu-negative metamaterial filter based isolation technique for MIMO antennas. *IEEE in Electronics Letter* **53**, 644–646.
11. **Mookiah P and Dandekar KR** (2009) Metamaterial substrate antenna array for MIMO communication system. *IEEE Antennas and Wireless Propagation Letters* **57**, 3283–3292.
12. **Jusoh M, Jamlos MF, Kamarudin MR and Malek F** (2012) A MIMO antenna design challenges for UWB application. *Progress in Electromagnetic Research B* **36**, 357–371.
13. **Palandoken M, Grede A and Henke H** (2009) Broadband microstrip antenna with left-handed metamaterial. *IEEE Antennas and Wireless Propagation Letters* **57**, 1468–1471.
14. **Nordin MAW, Islam MT and Misran N** (2013) Design of a compact ultra wideband metamaterial antenna based on the modified split ring resonator and capacitively loaded strips unit cell. *Progress in Electromagnetic Research* **136**, 157–173.
15. **Nandi S and Mohan A** (2017) A compact dual band MIMO slot antenna for WLAN application. *IEEE Antennas and Wireless Propagation Letters* **16**, 2457–2460.
16. **Mallahazedh AR, Es'haghi S and Alipour A** (2009) Design of an E shaped MIMO antenna using two algorithms for wireless application at 5.8 GHz. *Progress in Electromagnetic Research B* **90**, 187–203.
17. **Yu XH, Wang L, Wang HG, Wu XD and Shang YH** (2012) A novel multiport matching method for maximum capacity of an indoor MIMO system. *Progress in Electromagnetic Research* **130**, 67–84.
18. **Toktas A and Akdagli A** (2014) Wideband MIMO antenna with enhanced isolation for LTE, WiMAX and WLAN mobile handsets. *Electronics Letter* **50**, 723–724.
19. **Kim SH, Lee JY, Nguyen TT and Jang JH** (2013) High performance MIMO antenna with 1-D EBG ground structures for handset applications. *IEEE Antennas and Wireless Propagation Letters* **12**, 1468–1471.
20. **Krairiksh M, Keowsawat P, Phongcharoenpanich C and Kosulvit S** (2009) Two probe excited circular ring antenna for MIMO application. *Progress in Electromagnetic Research* **97**, 417–431.
21. **Parchin NO, Al-Yasir YIA, Ali AH, Elfergani ISSA, Noras JM, Rodriguez J and Abd-Alhameed RA** (2019) Eight element dual polarized MIMO slot antenna system for 5 G smart phone applications. *IEEE Access* **7**, 15612–15622.
22. **Barani IRR and Wong K-L** (2018) Integrated inverted-F and open-slot antennas in the metal-framed smartphone for 2*2 LTE LB and 4*4 LTE M/HB MIMO operations. *IEEE Transactions on Antennas and Propagation* **66**, 5004–5012.
23. **Chen YS and Chang CP** (2016) Design of four element multiple input multiple output antenna for compact long term evolution small cell base stations. *IET Microwaves, Antnnas and Propagation* **10**, 385–392.
24. **Chen Q, Lin H, Wang J, Ge L, Li Y, Pei T and Sim CYD** (2019) Single ring slot based antennas for metal rimmed 4G/5 G smartphones. *IEEE Transactions on Antennas and Propagation* **67**, 1476–1487.
25. **Das G, Sharma A, Gangwar RK and Sharawi MS** (2018) Compact back to back DRA based four port MIMO antenna system with bi-directional diversity. *Electronics Letters* **54**, 884–886.
26. **Deng JY, Li JY, Zhao L and Guo LX** (2017) A dual band inverted-F MIMO antenna with enhanced isolation for WLAN applications. *IEEE Antennas and Wireless Propagation Letters* **16**, 2270–2273.
27. **Ding Y, Du Z, Gong K and Feng Z** (2007) A four element antenna system for mobile phones. *IEEE Antennas and Wireless Propagation Letters* **6**, 655–658.
28. **Fan Y, Huang J, Chang T and Liu XY** (2018) A miniaturized four element MIMO antenna with EBG for implantable medical devices. *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology* **2**, 226–233.
29. **Li H, Xiong J and He S** (2009) A compact planar MIMO antenna system of four elements with similar radiation characteristics and isolation structure. *IEEE Antennas and Wireless Propagation Letters* **8**, 1107–1111.
30. **Hussain R, Sharawi MS and Shamim A** (2018) 4-element concentric pentagonal slot line based ultra wide tuning frequency reconfigurable MIMO antenna system. *IEEE Transactions on Antennas and Propagation* **66**, 4282–4287.
31. **Ramachandran A, Pushpakaran SV, Pezholil M and Kesavanth V** (2016) A four port MIMO antenna using concentric square ring patches loaded with CSRR for high isolation. *IEEE Antennas and Wireless Propagation Letters* **15**, 1196–1199.
32. **Saad AAR and Mohamed HA** (2019) Conceptual design of a compact four element UWB MIMO slot antenna array. *IET Microwaves, Antennas & Propagation* **13**, 208–215.
33. **Sarkar D, Singh A, Saurav K and Srivastava KV** (2015) Four element quad band multiple input multiple output antenna employing split ring resonator and inter digital capacitor. *IET Microwaves, Antennas and Propagation* **9**, 1453–1460.
34. **Sarkar D and Srivastava KV** (2017) A compact four element MIMO/diversity antenna with enhanced bandwidth. *IEEE Antennas and Wireless Propagation Letters* **16**, 2469–2472.
35. **Soltani S, Lotfi P and Murch RD** (2017) A dual band multiport MIMO slot antenna for WLAN applications. *IEEE Antennas and Wireless Propagation Letters* **16**, 529–539.
36. **Zhai Gh, Chen ZN and Qing X** (2015) Enhanced isolation of a closely spaced four element MIMO antenna system using metamaterial mushroom. *IEEE Transactions on Antennas and Propagation* **63**, 3362–3370.

K. Malaisamy M.E. was born in Tamilnadu, India. He is currently working as Assistant Professor, Department of Electronics and Communication Engineering, Saranathan College of Engineering, Tiruchirapalli, Tamilnadu, India. He has published eight papers in International Journals and has presented 10 papers in International and National Conferences in India. He is a life member of ISTE, ISSE. His current research interest areas are Antennas, RF and microwave devices.

M. Santhi M.E., Ph.D., was born in Tamilnadu, India in 1969. She is currently working as Professor & Head, Department of Electronics and Communication Engineering, Saranathan College of Engineering, Tiruchirapalli, Tamilnadu, India. She has 23 years of teaching experience. She is the reviewer in reputed journals like IEEE Transactions on VLSI, IEEE Access, Springer, etc. She has published 18 reputed international journals and 20 reputed international conferences. Her research areas are asynchronous techniques, MB-OFDM UWB, RF and microwave devices

S. Robinson M.E., Ph.D., was born in Tamilnadu, India in 1982. He is currently working as Associate Professor, Department of Electronics and Communication Engineering, Mount Zion College of Engineering and Technology, Pudukkottai, Tamilnadu, India. He has published more than 100 papers in International Journals and presented more than 100 papers in International and National Conferences in India and foreign countries. He has published one book and five books chapters. He is the reviewer for around 25 refeeed journals like IEEE, SPIE, Elsevier, Springer, PIER, and HJEEE Journals. He is a life member of ISTE, IETE, CSI, IE (I), and member of IEEE. His current research interests are in the areas of Optical Communication, Photonic Crystals, Photonic Integrated Circuits, Optical Devices, Microwave communication, Microwave Devices, and Optical Networks.

https://doi.org/10.1017/S1759078720001658 Published online by Cambridge University Press