IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 15, Issue 2 Ser. II (Mar – Apr 2020), PP 08-13
www.iosrjournals.org

Design and Analysis of a Compact MIMO Textile Antenna with Improved Mutual Coupling for WBAN Applications

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Abstract: *This paper proposes a miniaturized high-isolation MIMO textile antenna for 2.4GHz ISM band Wireless Body Area Network (WBAN) applications. An inverted S-type radiating element is used to reduce the overall dimension of the proposed MIMO textile antenna with very compact size of 86 mm×40 mm×1.6 mm. The proposed MIMO antenna consists of S shaped type radiator, ground and two slots. The Defected Ground Structure (DGS) are introduced in the shared ground plane of the proposed MIMO textile antenna to produce high isolation between the antenna elements. By putting two slits in a ground plane the isolation characteristic is improved and the resonant frequency can be controlled. In general, textiles present a very low dielectric constant that reduces the surface wave losses and increases the performance of the antenna. The proposed MIMO textile antenna has been designed on jeans substrate with dielectric constant εr = 1.6 and 1.6mm thickness. The proposed MIMO textile antenna has very low mutual coupling of (S21 < -25dB), low envelop correlation coefficient (ECC < 0.001), high Diversity Gain (DG > 9.5 dB and peak gain is around 3.0 dBi. The proposed antenna observed good performance in terms of S-parameters, radiation properties, mutual coupling, and diversity gain (DG), envelop correlation coefficient (ECC). The proposed MIMO textile antenna is competitive for wearable applications, due to its compact size, single-layer structure, easy integration and robustness.*

Date of Submission: 22-03-2020 Date of Acceptance: 09-04-2020

I. Introduction

The rapid advances in communication technologies have led to the use of the wearable wireless body area network (WBAN) for various applications such as medical devices, police and military agencies, sports training, entertainment, and wearable computing etc. [1]. The antennas used for WBAN require a small size, a low human body effect, and a low specific absorption ratio (SAR) [2]. The human body has a high dielectric constant with a high loss tangent and low conductivity at the microwave frequency band. Therefore, the gain and radiation efficiency of an antenna can be reduced when an antenna is operated on or within the human body.

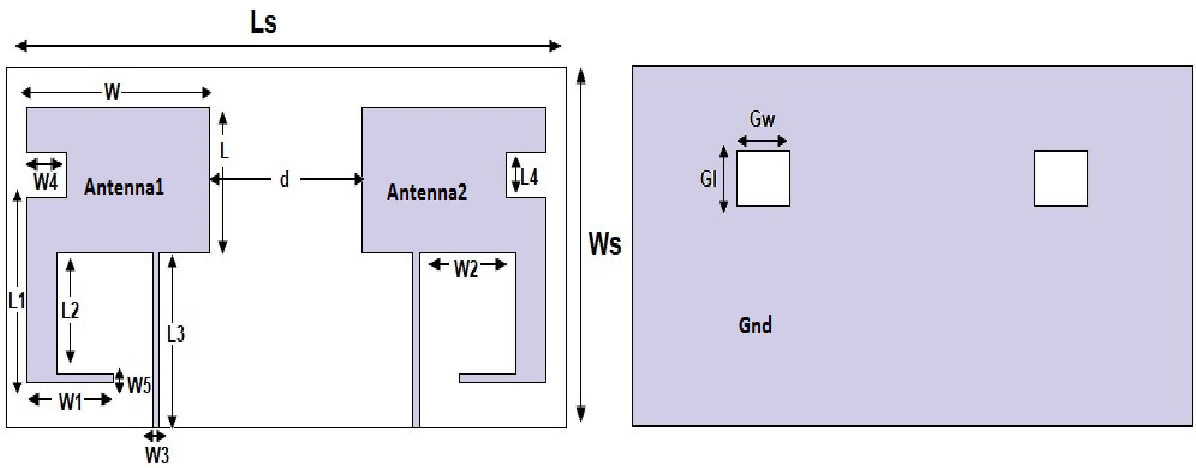
Recently, much work has been done to investigate the on-body communication channel at the Industrial, Scientific and Medical(ISM) band [3][5]. In a WBAN system, multipath propagation can occur due to reflections from the surrounding environment and the body parts. In addition, multipath fading can occur in response to the large relative movements of body parts, shadowing, polarization mismatch, and scattering by the body and the surrounding environment [3].This harsh WBAN communication environment has been addressed by the recent proposal of various diversity techniques [6]. The placement of two antennas close to each other requires an isolation between the antennas that is sufficiently high to minimize the mutual effects. Many researchers have conducted various studies on the performance analysis of on-body WBAN communication systems in the industrial, scientific, and medical (ISM) bands [8–10]. Because of reflections/scatterings that occur in a neighborhood environment and/or on the human body, severe multipath fading can arise in on-body communication links [9]. Multipath fading not only decreases the communication reliability of multi signals but also worsens the efficiency of a WBAN system [11]. To improve communication performance under the influence of multipath fading, a diversity technique such as multiple-input and multiple output (MIMO) is necessary.

This paper proposes a miniaturized high isolation diversity antenna for wearable WBAN applications in the 2.4GHz. An inverted-S shaped antenna is used to achieve a compact size of an antenna for on-body communication. Two antenna elements are placed on the same substrate with a small slits in ground element in order to improve the performance and overcome multipath fading. A compact MIMO textile antenna is presented in this paper having very low mutual coupling (S21 < -25dB) between the MIMO radiating elements. The performance parameters of the proposed diversity antenna including the S-parameter characteristics, radiation patterns envelope correlation coefficient (ECC), and Diversity Gain (DG) are analyzed using HFSS simulation tool.

II. Antenna Characterization

The configuration of the proposed diversity MIMO textile antenna is shown in Fig. 1(a). The Top view proposed diversity antenna consists of inverted S shape type radiator and slots in ground plane. A slit in ground plane is placed below each antenna elements. The two antenna elements of the diversity antenna are a separation distance of 23mm (0.17λ) in the y-axis direction. Each antenna element has a dimension of 28 mm×16 mm and is fed by a 50 Ω microstrip line. Fig. 1(b) shows the bottom view that is used to enhance the isolation characteristics at the ISM band. The ground plane is composed of a 1.6mm Jeans substrate with a relative dielectric constant of 1.6 and a slot size of 6.0 mm×8.2 mm.

A second antenna of the same shape is placed near to it as shown in Fig. 1 (a) having shared ground plane of proposed MIMO textile antenna. Greater space is achieved between the antenna elements for better isolation by using DGS techniques.



(a) TOP VIEW (b) BOTTOM VIEW

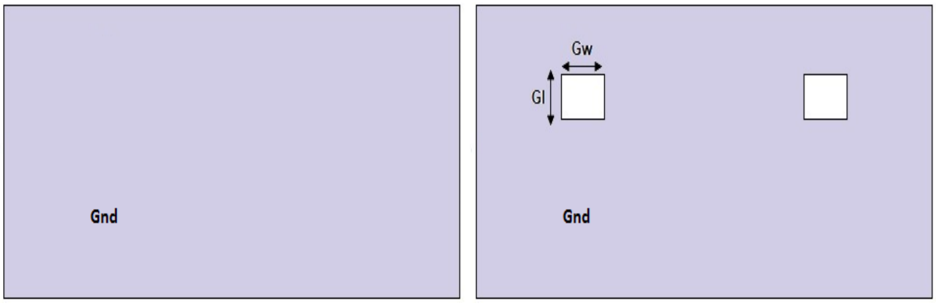
Fig. 1 Proposed MIMO Textile Antenna

Table I: Optimized Parameters of Proposed MIMO Textile Antenna

Parameters	Dimension (mm)	Parameters	Dimension (mm)
L	16.0	Ls	40.0
W	28.2	Ws	86.0
L1	20.5	W1	13.3
L2	13.5	W2	14.6
L3	19.5	W3	2.0
L4	5.0	W4	5.0
L5	7.8	W5	1.0
D	23.0	W6	1.5
Gl	6.0	Gw	8.2

III.Results And Discussion

Simulation of proposed MIMO textile antenna has been carried out in HFSS. In the first stage, a plane solid groundwere designed and tested for the desired results (Antenna without DGS), then it is modified by adding slots in the ground plane (Antenna with DGS). It is worth noticing that low mutual coupling is always desirable for high performance MIMO antennas



(a) Without DGS ground (b) With DGS ground

Fig.2. Proposed MIMO antenna with modifications in ground plane

It can be seen that antenna without DGS has poor isolation in the whole 2.4Ghz band when the conventional solid ground plane is used. Mutual coupling between the proposed antennas is reduced by modifying the ground plane with DGS techniques..

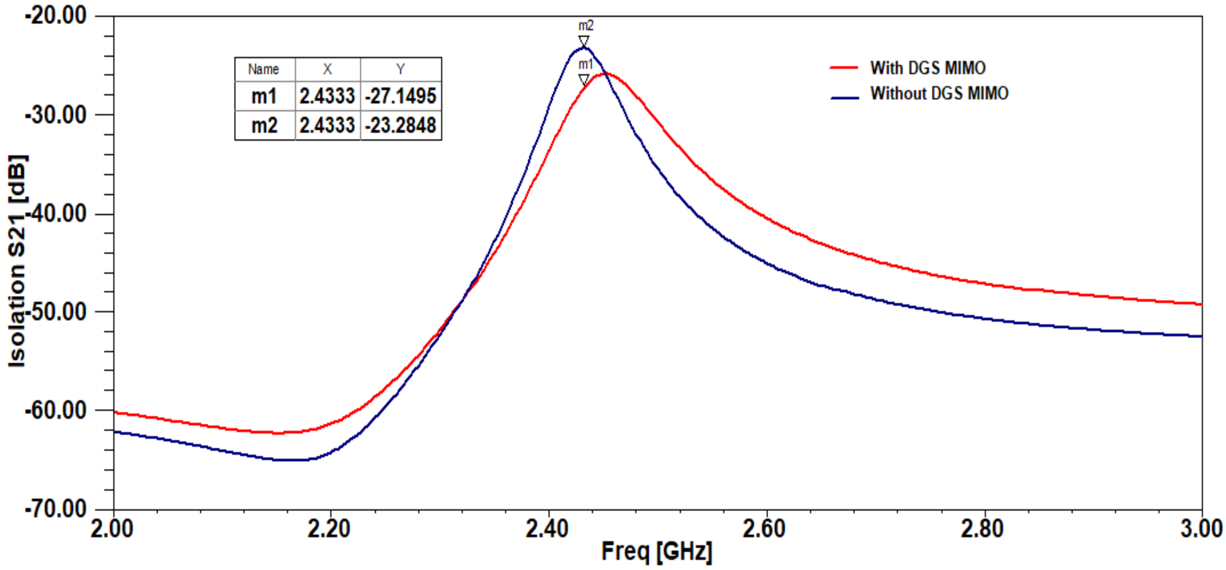


Fig.3. Effect of DGS on S21 parameters

High isolation between the MIMO antenna elements is achieved by adding slot in ground plane. It shows that more than -25 dB of isolation is produced by inserting DGS.

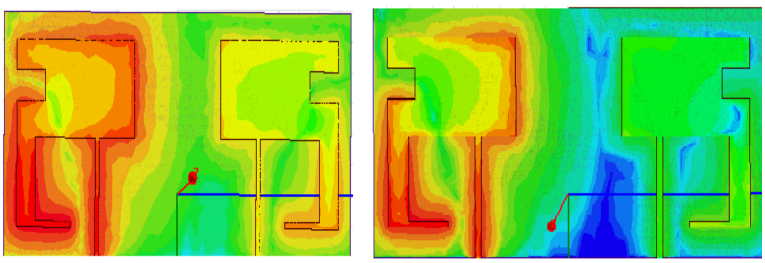


Fig.4. Current distributions of the proposed diversity MIMO antenna at 2.45 GHz (a) Without DGS MIMO (b) with DGS MIMO

The simulated S-parameter characteristics obtained with & without the DGS are shown in Fig. 3. The effect of the slot in ground on the isolation characteristics is investigated by analyzing the current distributions at 2.45 GHz with and without slot in ground, as shown in Fig. 4. When one of the two elements is excited, a strong current is induced in the other element in the absence of the DGS. After the inserting slot in ground, the induced current in the non-excited element weakens.

A.S-Parameters

Fig. 5 shows the simulated S-Parameters for the designed MIMO textile antenna.

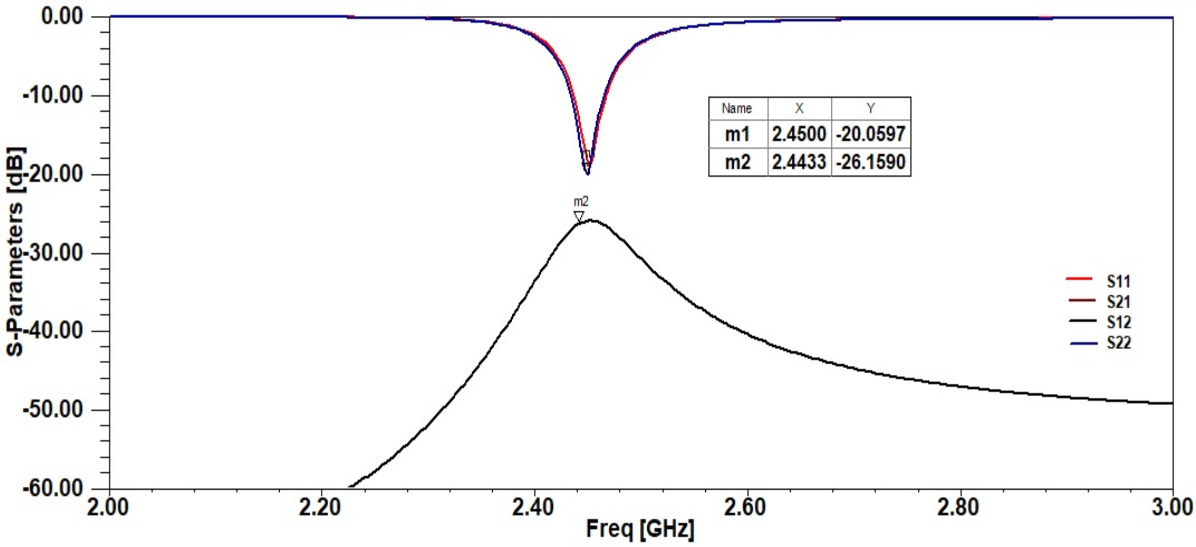


Fig.5 Simulated S-parameters of proposed MIMO Textile antenna.

The proposed textile MIMO antenna covers 2.42 GHz to 2.47 GHz bandwidth with S11/S22 < -10 dB and High isolation S21/S12 < -25 dB is achieved throughout 2.4 GHz band.

B. Radiation Pattern and Gain

Simulated radiation pattern of the proposed MIMO textile antenna are plotted in Fig. 6. The proposed antenna has a unidirectional pattern in both E and H plane (Fig. 7), which is beneficial for wearable antennas when it is attached to the human body.

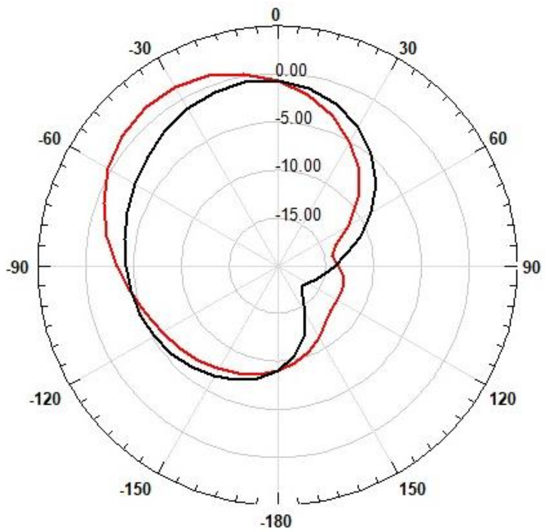


Fig 6. Radiation patterns for the proposed MIMO textile antenna in E Plane (red) and H plane (black) 2.4 GHz

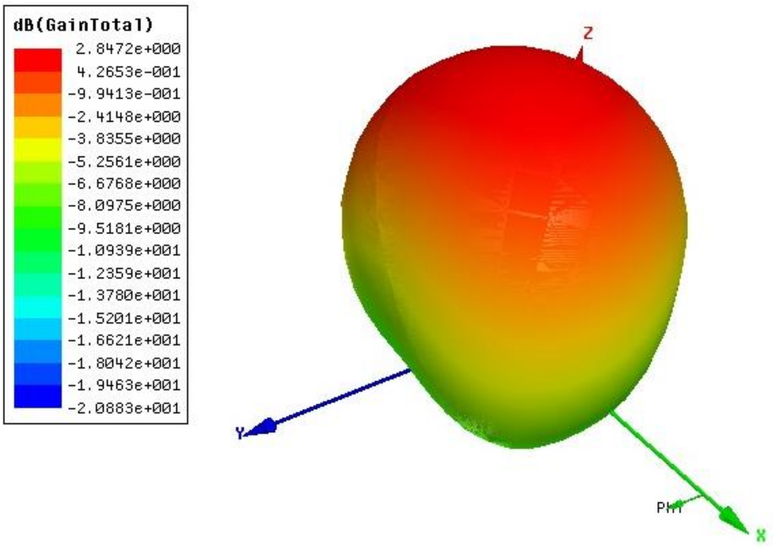


Fig 7. 3D Gain of proposed MIMO textile antenna

It is observed that the radiation patterns of MIMO textile antenna are directional in both E-plane & H plane as shown in Fig.6 at 2.4GHz and maximum gain is 2.8dB at 2.4GHz which is shown in Fig 7.

C. Diversity Analysis

To validate the capability and performance of the proposed MIMO Textile antenna, it is necessary to have low envelope correlation coefficient (ECC). The ECC can be evaluated using S-parameters by the following relation

$$ECC = \frac{|S_{11}^{*}S_{12} + S_{21}^{*}S_{22}|^2}{(1 - |S_{11}|^2 - |S_{21}|^2)(1 - |S_{22}|^2 - |S_{12}|^2)} \qquad (4)$$

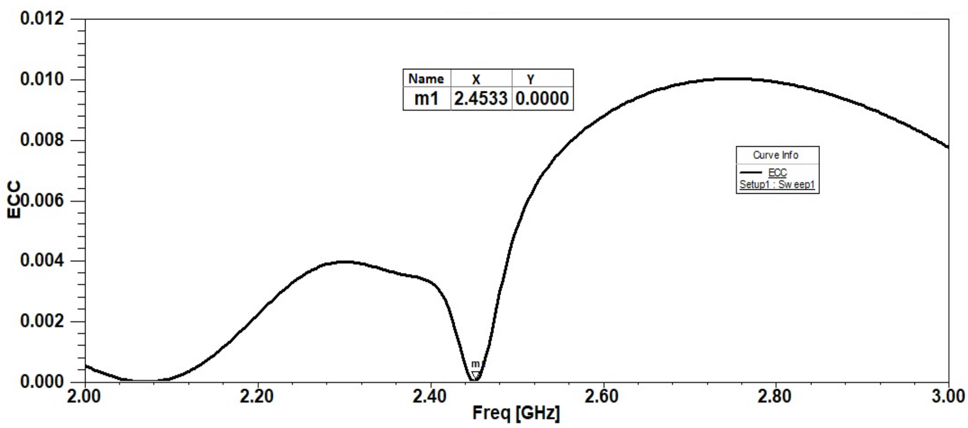


Fig 8. Simulated ECC of the proposed MIIMO Textile antenna

ECC should have ideally zero value but practical limit for an uncorrelated MIMO antenna is ECC < 0.5. The ECC of the proposed MIMO textile antenna has ECC less than 0.001. Fig. 8 shows the ECC of the proposed MIMO antenna. It can be noticed from the Fig. 8 that the proposed antenna has ECC < 0.001 for the entire 2.4 GHz band. This leads us to expect good performance in terms of diversity. Another important parameter for MIMO antenna performance is its diversity gain (DG). The diversity gain of the MIMO antenna can be calculated using the following relation.

$$DG = 10\sqrt{1 - (ECC)^2} \qquad (5)$$

Where ECC is the envelop correlation coefficient

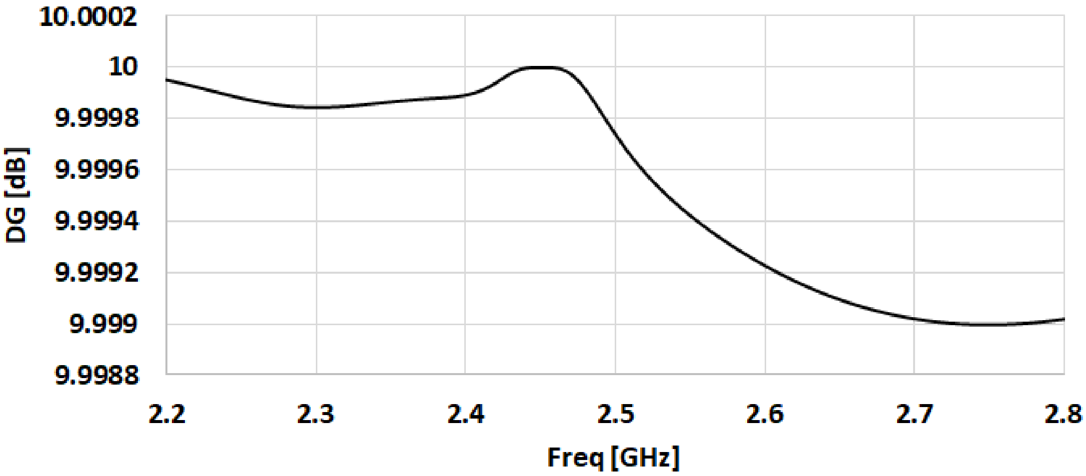


Fig 9. Simulated diversity gain of the proposed MIMO Textile antenna

Fig. 9 shows the DG with varying frequencies. It is noted from that the proposed MIMO textile antenna has diversity gain (DG > 9.95 dB) for the entire 2.4GHz band.

IV.Conclusion

A high isolation MIMO textile antenna is designed to operate in the 2.4GHz ISM band for WBAN applications. A DGS consisting of a two slots, is added below each radiator to improve the isolation. The isolation characteristic is improved by adding two slits in ground. Theisolation of textile MIMO antenna is higher than -25dB over the 2.4GHz ISM band. The proposed MIMO textile antenna has a compact dimension of 86mm×40mm×1.6mm. The resonant frequency can be controlled by the S shaped type radiator. Therefore, the above-mentioned properties proves that the proposed MIMO antenna is suitable for WBAN applications.

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Tejaswini Ashtankar,etal." Design and Analysis of a Compact MIMO Textile Antenna with Improved Mutual Coupling for WBAN Applications." *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)*, 15(2), (2020): pp. 08-13.