Electronics and Electrical Engineering

AIMS Electronics and Electrical Engineering, 3(3): 224–232.
DOI: 10.3934/ElectrEng.2019.3.224
Received: 22 March 2019
Accepted: 23 May 2019
Published: 05 June 2019

http://www.aimspress.com/journal/ElectrEng

Research article

A two-element antenna array for compact portable MIMO-UWB communication systems

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Abstract: In this paper, a compact multiple input multiple output (MIMO) antenna with the size of 44 mm × 27 mm × 0.8 mm is designed for operation in ultra-wideband (UWB) frequency range, i.e., from 3.1 GHz to 10.6 GHz. The design consists of two parallel and symmetric radiators fed with coplanar waveguide (CPW) and printed on the same side of a substrate. To enhance isolation and increase impedance bandwidth, a T-shaped slot is etched out of the ground plane. Simulations are employed to design the two antenna elements and to study their performance in terms of reflection coefficient, mutual coupling, current distribution, radiation pattern, and envelope correlation coefficient (ECC) for pattern diversity. Simulated and measured results show that the impedance bandwidth of the proposed antenna covers the whole UWB frequency range with an isolation of better than −15 dB between the two elements. Measured results show that the proposed antenna is a good candidate for portable MIMO/diversity UWB applications.

Keywords: UWB antennas; MIMO antennas; wireless communication

1. Introduction

Ultra-wide band (UWB) technology using frequencies from 3.1 GHz to 10.6 GHz [1] offers high speed data rate, extremely low spectral power density, high precision ranging, low cost, and low complexity. Multiple input and multiple output (MIMO) antennas used in UWB systems improve system's performance by providing increased data rates and increased range through beam-forming [2]. Antenna diversity is a well-known technique to enhance the performance of MIMO systems by mitigating the multipath fading and co-channel interference. Thus, MIMO/diversity antennas covering UWB frequency range and having good radiation patterns and diversity performance have become the focus of wireless communications.

Several UWB MIMO antennas have been designed in the past. The focus of these studies has been on reducing the size of the antenna while enhancing the isolation. To improve the isolation between the elements, in [3], the shape of the ground plane has been optimized and radiators have been notched. These have greatly suppressed the mutual coupling through the common ground plane. Also, the orthogonal configuration for the radiating elements has reduced the mutual coupling even further. However, this design fails to provide impedance match at frequencies above 5 GHz. In [4], a tree-like isolation structure has been inserted between two UWB diversity radiating elements. The antenna covers the whole UWB frequency range and has dimensions of 40 mm × 35 mm (covering an area of 1400 mm^2). In [5], two UWB MIMO elements with different polarizations and patterns were integrated in a compact USB dongle for isolation enhancement. The antenna covers the lower UWB band of 3.1–5.15 GHz. In [6], a compact MIMO antenna with a small size of 40 mm × 26 mm (covering an area of 1040 mm^2) has been proposed for portable UWB applications. The antenna consists of two microstrip-fed planar-monopole elements printed on the same side of the substrate and placed perpendicular to each other to achieve good isolation. To enhance isolation and improve impedance bandwidth, two long protruding ground stubs are added to the ground plane on the other side and a short ground strip is used to connect the ground planes of the two planar-monopoles together to form a common ground. In [7], miniaturized double-layer electromagnetic band-gap (EBG) structures have been etched on the ground plane for broadband mutual coupling reduction. The antenna operates from 3 GHz to 6 GHz. In [8], a broadband neutralized line has been employed for the decoupling of elements in a compact UWB MIMO antenna. The designed antenna covers the lower part of UWB frequency range from 3.1 GHz to 5 GHz with the mutual coupling between the elements lower than 22 dB. The antenna dimensions are 35 mm × 16 mm (covering an area of 560 mm^2).

In this paper, the design of a two-element UWB MIMO antenna fed by co-planar waveguide (CPW) is presented. CPW feeding provides an easy means of parallel and series connection with active and passive elements that are required for matching and gain improvement. It also eases the integration of the proposed antenna with monolithic microwave integrated circuits (MMIC) [9]. The antenna is designed via full-wave simulations and the measured scattering parameters of the fabricated prototype are compared with the simulation results. Satisfactory performance of this antenna array is demonstrated in terms of impedance match, radiation pattern, and envelope correlation coefficient. The parametric study of the major influencing parameters is also presented.

2. Proposed diversity antenna structure

In the proposed antenna, two UWB radiating elements are designed over a compact area for MIMO applications. The two elements are identical and they are fed by CPW feedlines. The structure is designed to be as small as possible and with the specifications of $|S_{11}|$ below −10 dB and $|S_{21}|$ below −15 dB over the UWB frequency range. We implemented the design with V-shaped radiators as shown in Figure 1(a). The motivation for this radiator shape is to have smooth transition of currents from the CPW feedline to the radiator elements.

In the structure, we employ FR4 substrate with electrical properties of ε_r = 4.4 and tanδ = 0.026 and substrate height of H = 0.8 mm. This selection is due to the fact that FR4 material is a common and cost-effective substrate in circuit board technology. However, it is worth noting that the loss for FR4 substrate reduces the antenna efficiency, in particular, at the higher portion of the UWB frequency range. If the cost and the integration with the rest of the communication circuitry allows, it would be best to use materials with lower loss (lower tanδ), such as Rogers substrates, in the antenna structure. In such case, the dimensions of the antenna need to be re-optimized.

FEKO software [10] was employed for performing the design process. In the simulation model, we also included the SMA connector feeding the antenna via CPW line. Both coaxial cable and the CPW line were designed in FEKO to have characteristic impedance of 50 Ω. The antenna elements and the ground plane in Figure 1(a) were designed to fulfill the specifications described above. This involved a rigorous and comprehensive study of the effect of various geometrical parameters on the performance of the antennas. A unique feature of FEKO software called "fitted spine" is employed to have smooth corners for the structure in our design leading to less reflections of the currents toward the feed points. This led to better impedance match over the UWB frequency range.

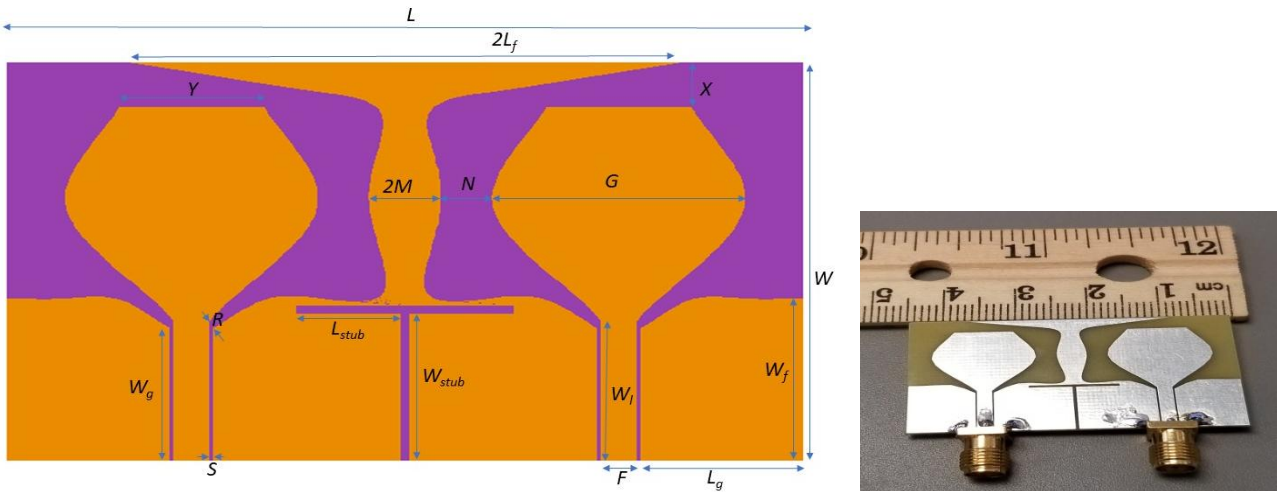

Figure 1. (a) Geometry of the proposed antenna array consisting of two V-shaped radiators fed by CPW transmission lines and a defected ground plane, (b) Fabricated antenna array.

Table 1. Values of the geometrical parameters for the designed UWB MIMO antenna.

Parameter	Value (mm)	Parameter	Value (mm)
L	44	W_l	9.5
W	27	F	2
H	0.8	R	1.62
L_g	9	S	0.19
W_g	9	G	14
$2L_f$	30.76	N	2.81
W_f	11	$2M$	4
W_{stub}	8	Y	8
L_{stub}	6	X	3

Table 1 shows the values of the optimal parameters. The overall size of the antenna is 44 mm × 27 mm × 0.8 mm. A parametric study of the major influencing parameters will be presented in Section 3.

To verify the performance of the proposed antenna, a prototype has been fabricated as shown in Figure 1(b). The fabricated UWB MIMO elements are fed by two thin coaxial cables and SMA connectors.

Figure 2 shows the simulated and measured scattering parameters of this antenna array. It is observed that satisfactory impedance match is obtained from both simulated and measured results. Also, excellent decoupling (well below −15 dB) is observed for $|S_{21}|$ which confirms the good performance in a MIMO system.

Some mismatches are observed between the simulation and measurement results which are smaller in some frequency bands and larger at others. While fine meshing has been used in FEKO simulations to ensure accuracy, we believe these mismatches are mainly due to the soldering effects as CPW-fed antennas are very sensitive to this effect. Soldering influences the field distributions of a CPW line leading to some unexpected results. Despite these issues, the values of measured $|S_{11}|$ and $|S_{21}|$ fulfill the specifications over almost all UWB frequency range.

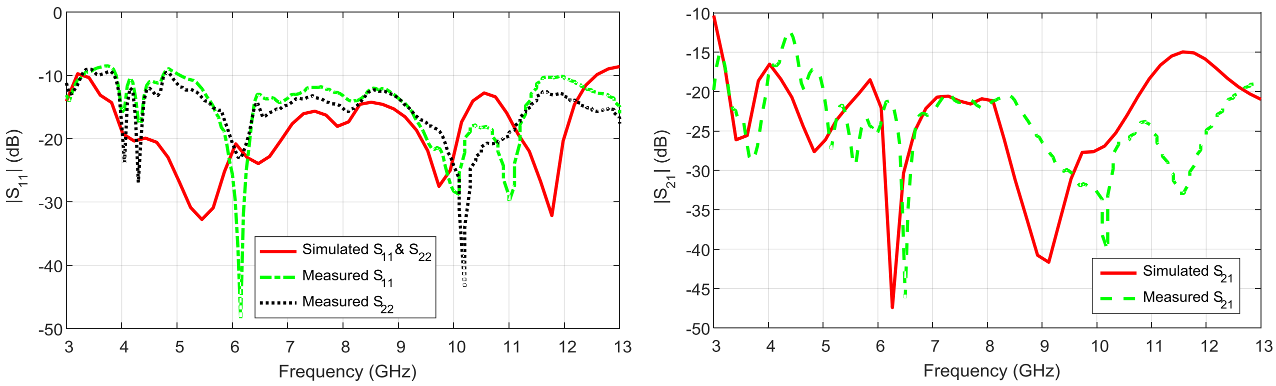

Figure 2. Measured and simulated (a) reflection coefficient and (b) transmission coefficient of the proposed UWB MIMO/diversity antenna.

3. Parametric study for the antenna structure

In this section, the parametric study of important influencing parameters and features in the antenna structure is presented. With reference to Fig. 1(a), the parameters and features that are analyzed include: 1) length of the upper portion of the ground plane L_f, 2) length of the vertical slot W_{stub}, and 3) length of the horizontal slot L_{stub}. Besides, we study the effect of presence of the T-shaped slot.

Figure 3 shows the variations of $|S_{11}|$ and $|S_{21}|$ parameters, respectively, for three different values of L_f including 10 mm, 15.38 mm, and 22 mm. Form these figures, it is observed that parameter L_f plays an important role in impedance matching, in particular, at lower frequencies. This is due to the fact that longer metallization supports currents associated with longer wavelengths (lower frequencies). From this study, the optimal value of L_f is determined to be 15.38 mm for the best impedance match.

To study the effect of the length of vertical stub W_{stub}, we assume that the design has only the vertical part of the T-shaped slot. Figure 4 shows the variations of $|S_{11}|$ and $|S_{21}|$ parameters, respectively, for three different values of W_{stub} including 8 mm, 9 mm, and 10 mm. From these figures, no noticeable variations are observed for these three values of W_{stub}. At this point, we also noticed that the width of the slot is not an important parameter. We have chosen a width of 0.5 mm for this vertical slot.

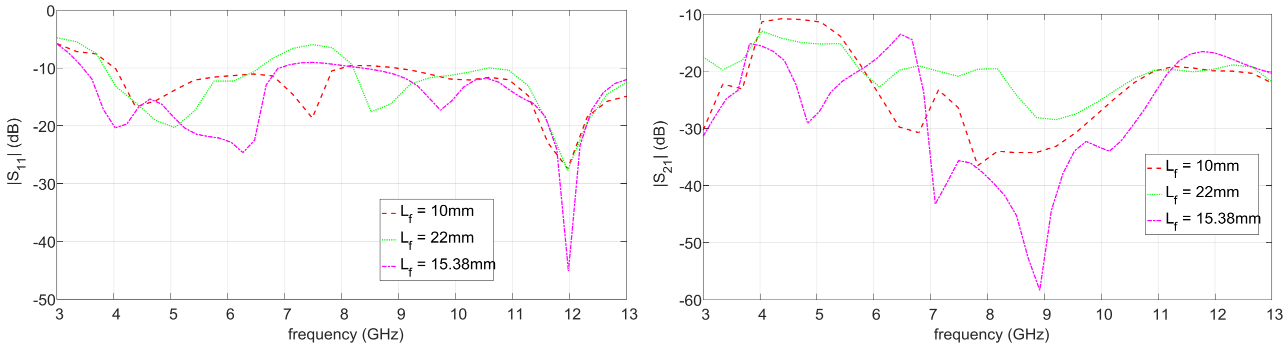

Figure 3. Variation of (a) $|S_{11}|$ and (b) $|S_{21}|$ for three values of L_f parameter for the proposed UWB MIMO/diversity antenna configuration.

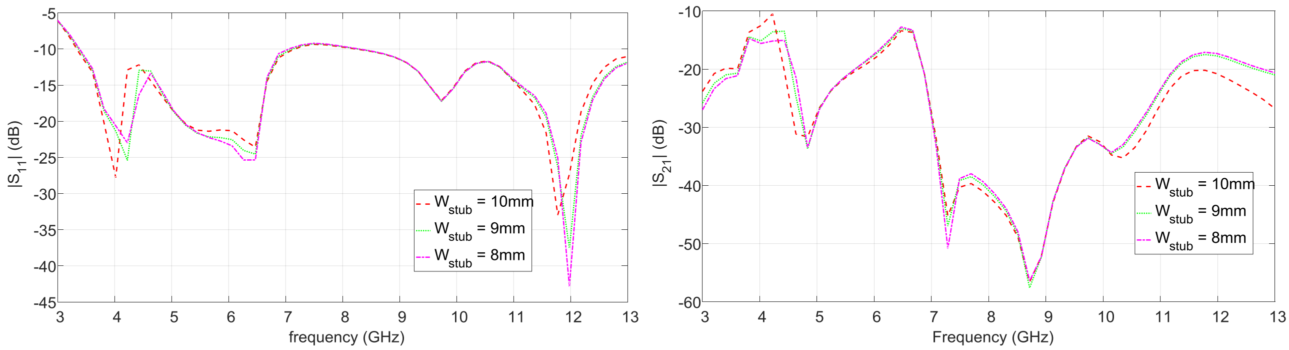

Figure 4. Variation of (a) $|S_{11}|$ and (b) $|S_{21}|$ for three values of W_{stub} parameter for the proposed UWB MIMO/diversity antenna configuration.

We study the effect of length of horizontal stub (L_{stub}), in the T-shaped slot. Figure 5 shows the variations of $|S_{11}|$ and $|S_{21}|$ parameters, respectively, for three different values of L_{stub} including 4 mm, 6 mm, and 8 mm. From these figures, the optimal value of L_{stub} = 4 mm is selected which ensures $|S_{11}| < -10$ dB over UWB frequency range and the lowest $|S_{21}|$ possible.

In general, it is observed from Figs. 4 and 5 that the variations of $|S_{11}|$ and $|S_{21}|$ are not so drastic for the studied values of W_{stub} and L_{stub}. It is also worth noting that when the horizontal and vertical slots are combined to form the T-shaped slot, further tuning is performed and the optimal values for W_{stub} and L_{stub} in the final design are 8 mm and 6 mm, respectively.

To further study the effect of having the T-shaped slot, we compare the values of $|S_{11}|$ and $|S_{21}|$ parameters with and without it in the final design (Figure 6). It is observed that drastic improvement is achieved for both $|S_{11}|$ and $|S_{21}|$ when the T-shaped slot is present. The only exception is that $|S_{21}|$ between 7 GHz and 9 GHz is lower when the T-shaped slot is absent but in this frequency range the value of $|S_{21}|$ with the T-shaped slot is still below −20 dB.

From the above-mentioned analysis and results, we can conclude that the design with L_f = 15.38 mm and T-shaped slot with W_{stub} = 8 mm and L_{stub} = 6 mm leads to the optimal performance in terms of impedance match and isolation within the UWB frequency range.

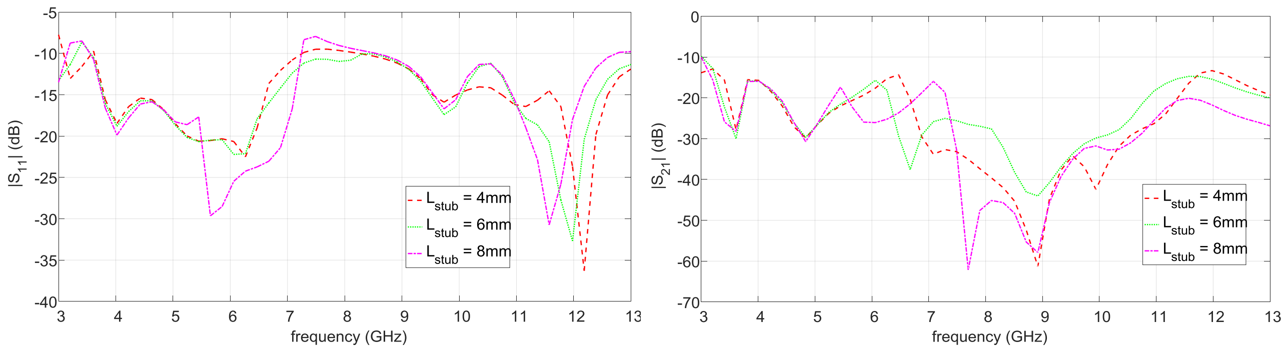

Figure 5. Variation of (a) $|S_{11}|$ and (b) $|S_{21}|$ for three values of L_{stub} parameter for the proposed UWB MIMO/diversity antenna configuration.

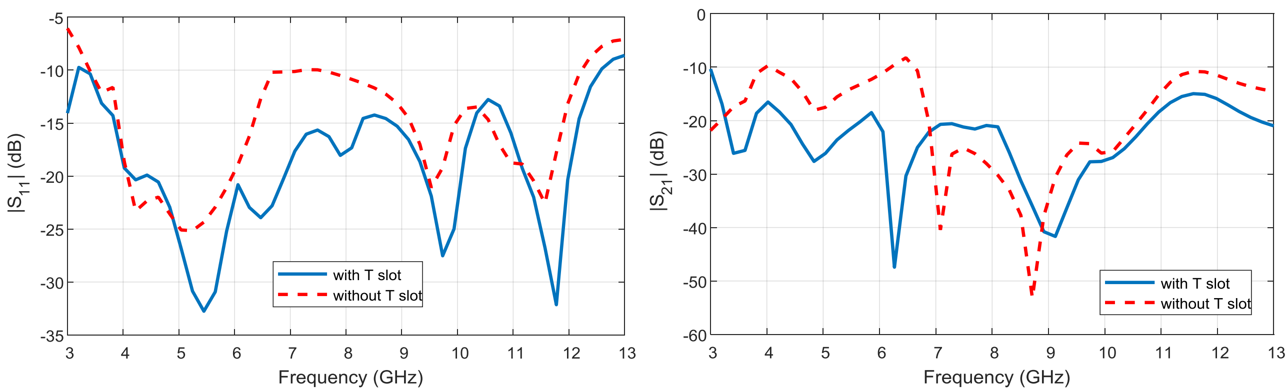

Figure 6. Variation of (a) $|S_{11}|$ and (b) $|S_{21}|$ with and without the presence of T-shaped slot for the proposed UWB MIMO/diversity antenna configuration.

4. Current distributions

Figure 7 shows the current distribution at the surface of the metalized regions at 3.2 GHz, 5 GHz, 6.46 GHz, 9.32 GHz, and 10.14 GHz for the designed antenna array shown in Fig. 1(a) when Port 1 is excited, with and without the T-shaped slot on the ground plane. It is clearly observed that when the T-shaped slot is not present, the current distribution on the radiator element corresponding to Port 2 is much stronger leading to larger coupling between the two elements. This degrades the performance, if this antenna is employed in a MIMO communication system. However, after introducing the T-shaped slot, the current distribution on the radiator element corresponding to Port 2 is significantly weakened leading to lower coupling between the two radiating elements. This, in turn, leads to improvement in the performance of a MIMO system.

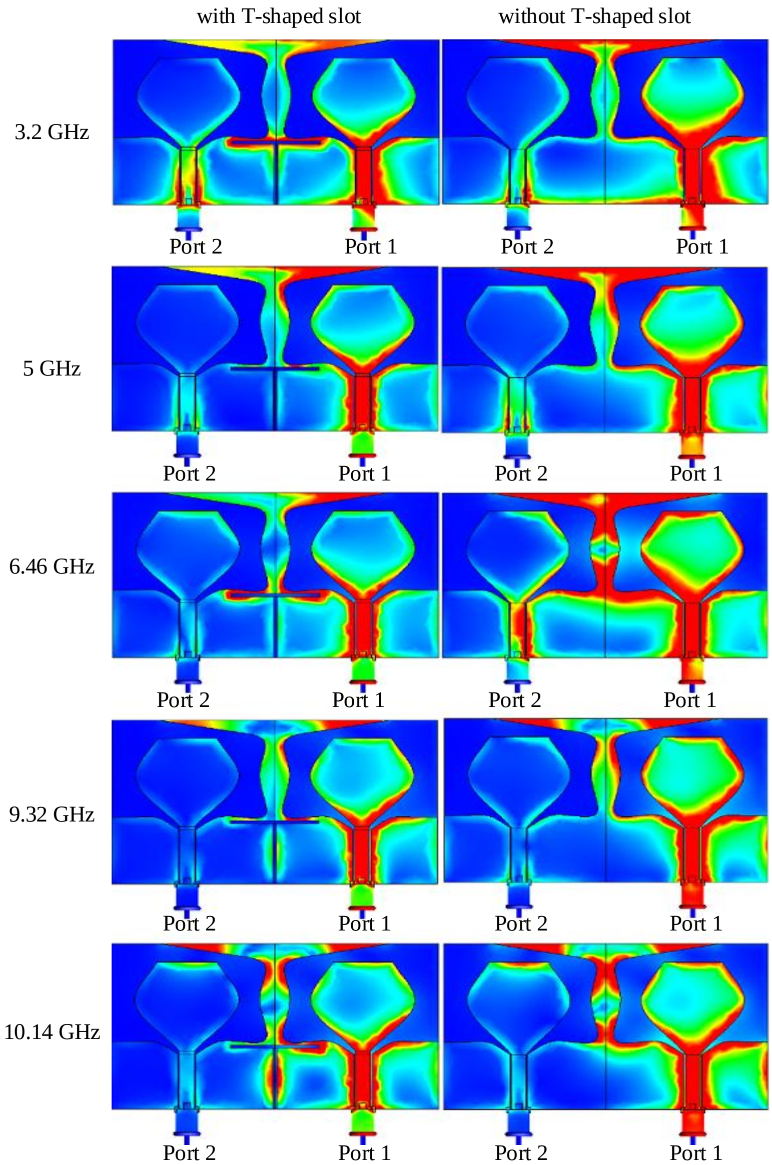

Figure 7. Surface current distributions with and without T-shaped slot when port 1 is excited at 3.20 GHz, 5 GHz, 6.46 GHz, 9.32 GHz, and 10.14 GHz.

5. Far-field radiation patterns for the proposed antenna

Three-dimensional (3D) antenna radiation patterns or plots are very important parameters for the antenna designer to evaluate how the antenna radiates power in various directions. Here, we show the radiation patterns for one of the elements of the antenna array while the other antenna is matched with 50 Ω load. Figure 8 shows the radiation patterns produced when Port 1 is excited and Port 2 is terminated with 50 Ω load and at frequencies 3.1 GHz, 5 GHz, 7 GHz, and 10.6 GHz. Since the two antenna elements are identical, the patterns produced when Port 2 is excited will be similar but mirrored with respect to the plane of symmetry. At 3.1 GHz almost omni-directional radiation pattern is achieved. At 5 GHz, the pattern starts to deviate from the omni-directional shape and at 7 GHz and 10.6 GHz the maximum radiation will be along the axis perpendicular to the plane of the antenna.

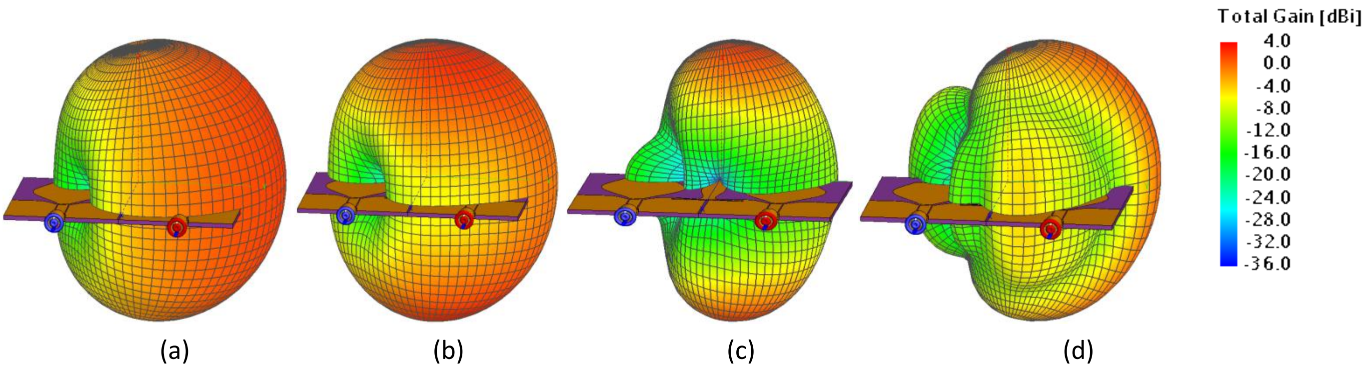

Figure 8. 3D far-field radiation patterns when Port 1 is excited and Port 2 is terminated with 50 Ω load at: (a) 3.1 GHz, (b) 5 GHz, (c) 7 GHz, and (d) 10.6 GHz.

6. Envelope correlation coefficient for the proposed antenna

Envelope correlation coefficient (ECC) is an important parameter to evaluate diversity performance. It depicts the extent of isolation or correlation of different communication channels. ECC can be computed from the scattering parameters of the antenna as [11]

$$\mathrm{ECC}=\frac{|S_{11}^{*}S_{12}+S_{21}^{*}S_{22}|}{\left(1-|S_{11}|^{2}-|S_{21}|^{2}\right)\left(1-|S_{22}|^{2}-|S_{12}|^{2}\right)} \tag{1}$$

Figure 9 shows the computed variation of ECC for the designed antenna. It is observed that the values of ECC are extremely low within UWB frequency range which is desirable when this antenna is employed in MIMO systems. In particular, it is below 0.04 from 4.1 GHz to 12 GHz.

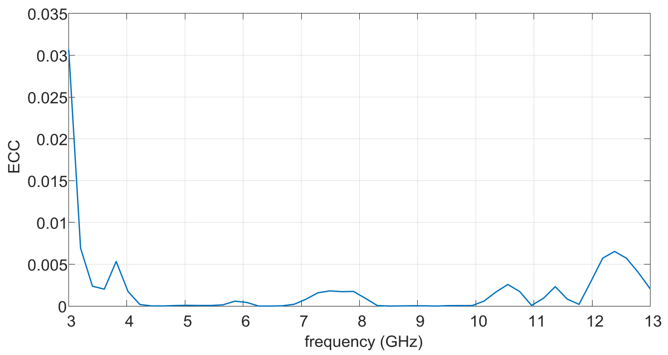

Figure 9. Envelope correlation coefficient (ECC).

7. Conclusions

In this paper, a compact antenna array was proposed for UWB MIMO communications. The dimensions of the two-element antenna array are 44 mm × 27 mm × 0.8 mm which are small enough for the antenna to be considered for portable wireless devices. The antenna is fed via CPW feedlines. This facilitates the connection of the antennas with active and passive elements (for matching and gain improvement) and integration with MMIC circuitry. The antenna has been fabricated on FR4 substrate and the experimental results confirm the UWB coverage for the proposed structure. The radiation pattern of the antenna elements is quasi omni-directional in particular at lower frequency range. To reduce coupling, a T-shaped slot was introduced as a decoupling structure between the two radiation elements. Besides, the computed ECC values for the antenna are extremely small over UWB frequency range confirming the excellent performance of the antenna in the UWB MIMO applications.

Conflict of interest

The authors declare that there is no conflict of interest.

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