

Original Research Article**No Frequency Reuse: Wearable Steerable MIMO Microstrip****Antenna Array for Mobile Ad Hoc Applications**

Abstract—The principle of eliminating the frequency reuse in the mobile Ad Hoc system among the sectors of the unit cell using MIMO antenna array is investigated in this paper. The size of the proposed antenna array is $10 \times 10 \text{ cm}^2$ to obtain a bandwidth around 1 GHz. The single antenna element is constructed from sub-patches that are connected with feeding network through pin diodes, as switches, that are mounted on an FR-4 substrate. The antenna elements are characterized from 0.8 GHz to 2 GHz in terms of S -parameters and radiation patterns with different switching OFF/ON categories. It is found that the proposed antenna behaves like highly directive end fire antenna at the main lobe direction around 1.5 GHz. Moreover, it is found that the antenna array exhibits insignificant coupling among each other around this frequency. A numerical investigation based on Finite Integral Techniques (FIT) is conducted using CST MWS to evaluate the antenna performance.

Index Terms—Ad Hoc, Array, Wearable, FIT.

I. INTRODUCTION

Decreasing the correlation between conventional antennas mounted on physically miniaturized arrays is one of the most substantial demands in MIMO systems [1]. However, convent antennas face a severe coupling in their arrays at the near-field due to the diffraction from finite-ground planes and

exterior surface waves [2]. Therefore, mutual coupling reduction has become a very demand feature in the design of antenna structure.

In the literature, several studies have been submitted to decrease the mutual coupling in the miniaturized antenna arrays [3]-[6]. In [3], a pure reactance was introduced between antennas at the resonance frequency to realize a separated network from connecting a lossless network between the input ports and the antenna ports. While in [4], transmission lines as antenna decouplers were involved to reduce the mutual coupling effects, however; such kinds of the decouplers are narrowband and restricted with the antenna bandwidth. The mutual coupling between antenna elements was mitigated in [5] through sharing a defected ground plane with resonant slits [5]. A different strategy was presented in [6] by introducing split-ring resonator magnetic inclusions between closely-separated monopole to increase the isolation.

We are investigated in this paper the use of directive sectors based on three patches to act as radiation directors to decrease the mutual coupling effects between the array sectors within a miniaturized profile. The proposed array performance is investigated using CST MWS numerical formulations [7]. The organization of this paper is stated as: In Section II, the proposed antenna array features are discussed. The performance of the antenna array is presented in Section III. Lastly, in Section IV, the accomplishments of the proposed paper are concluded.

II. ANTENNA DESIGN AND METHODOLOGY

The proposed antenna array is based on three main sectors mounted on a circular substrate and fed by coplanar transmission line network with three ports as seen in Fig. 1(a). The individual sector is constructed from three patches fed with a transmission line network as presented in Fig. 1(b).

47 Generally, the microstrip antenna array is shaped circularly; see Fig. 1(c), to achieve high diversity in
 48 the radiation patterns of the antenna elements. The patches and the ground planes are considered as
 49 PEC layer mounted on a lossy dielectric, $\epsilon_r=4.3$ and $\tan\delta=0.025$, FR-4 substrate. The three patches are
 50 separated with 120° rotationally around the z -axis at the origin. The dimensions and locations of the
 51 patches are listed in Table 1 according to Fig. 1(b). The location of the feeding position to the patch is
 52 listed in Table 1 from the center of the array.

53 **Table 1;** Patch dimensions, locations, and feeding position in (mm).

Patch	Dimensions (Major $\times$ Minor)	Location (x, y)	Feed ($X_{\text{offset}}, Y_{\text{offset}}$)
I	12×6	(22, 13)	(20, 7)
II	18×9	(22, -19)	(20, -6)
III	26×13	(40, -3)	(30, 0)

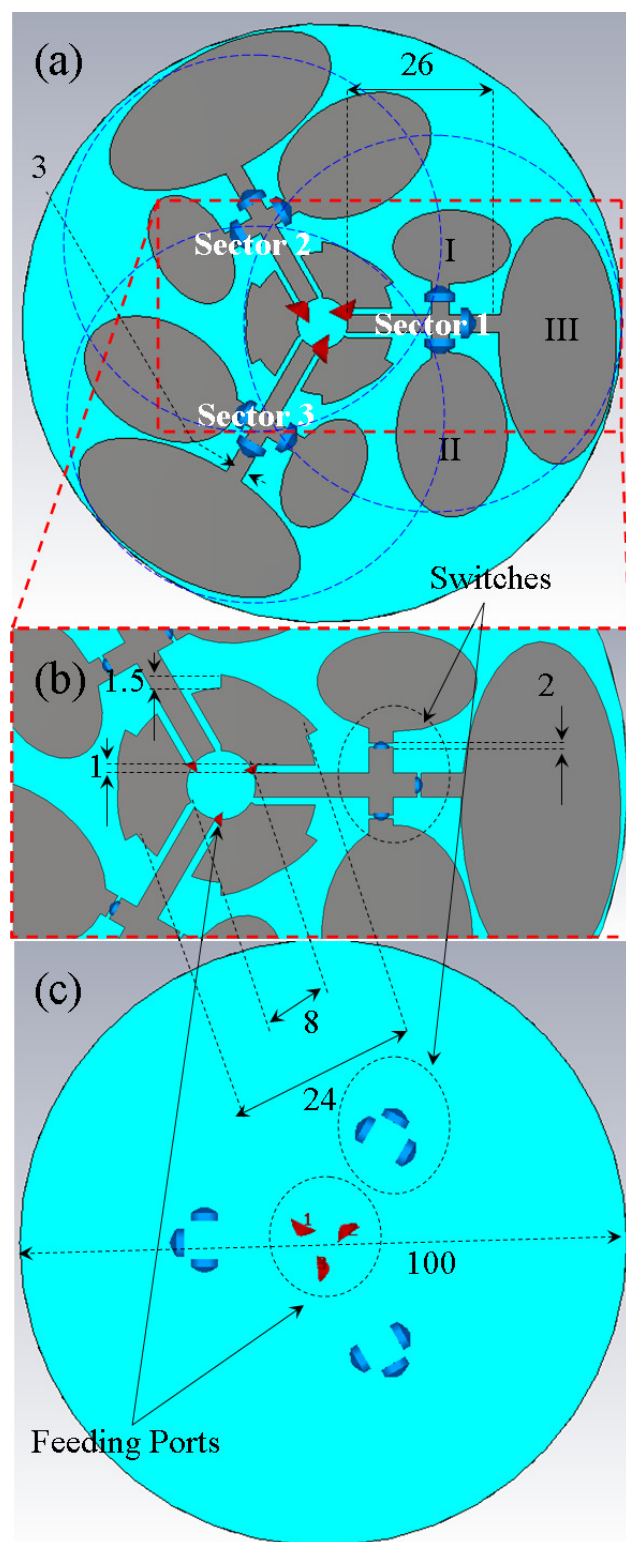


Fig. 1; Antenna dimensions and features in (mm): (a) Front panel, (b) Single antenna sector, and (c) Back panel.

III. ANTENNA PERFORMANCE AND DISCUSSION

To study the performance of the proposed antenna array, in terms of S-parameters, gain, and radiation patterns, a full wave simulation based on FIT formulations are invoked using CST MWS [9] as follow:

A- Antenna Performance based on Single Sector Element

A numerical study is performed on a single sector element to evaluate the S_{11} and radiation patterns in this section. It is found when all branches are ON; the sector exhibits three resonance modes as seen in the S_{11} as seen in Fig. 2. However, when the second patch is switched OFF only, two modes appear at 1.23 GHz and 1.83 GHz. By switching the first and the second patch OFF, the antenna shows a mode at 1.23 GHz, while the second mode is appeared due to the harmonic generation.

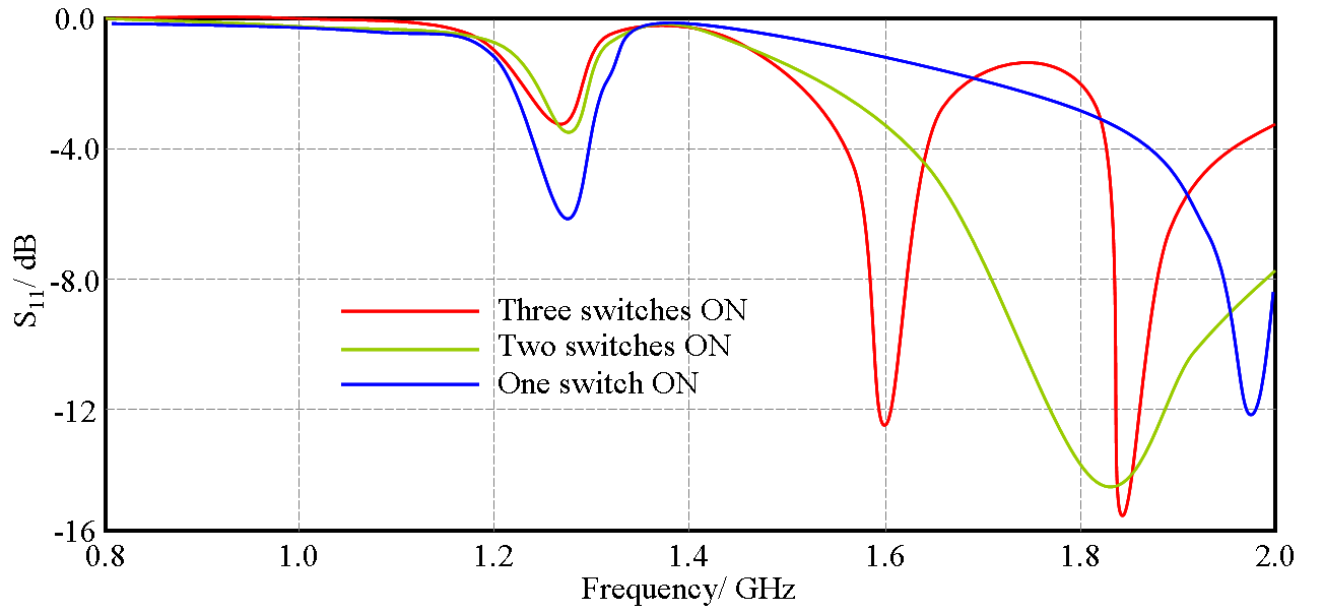


Fig. 2; The S_{11} spectra of the three patches of a single sector.

The radiation patterns of the antenna elements at the three scenarios are presented in Fig. 3 in the E - and H -planes at 1.2 GHz and 1.6 GHz.

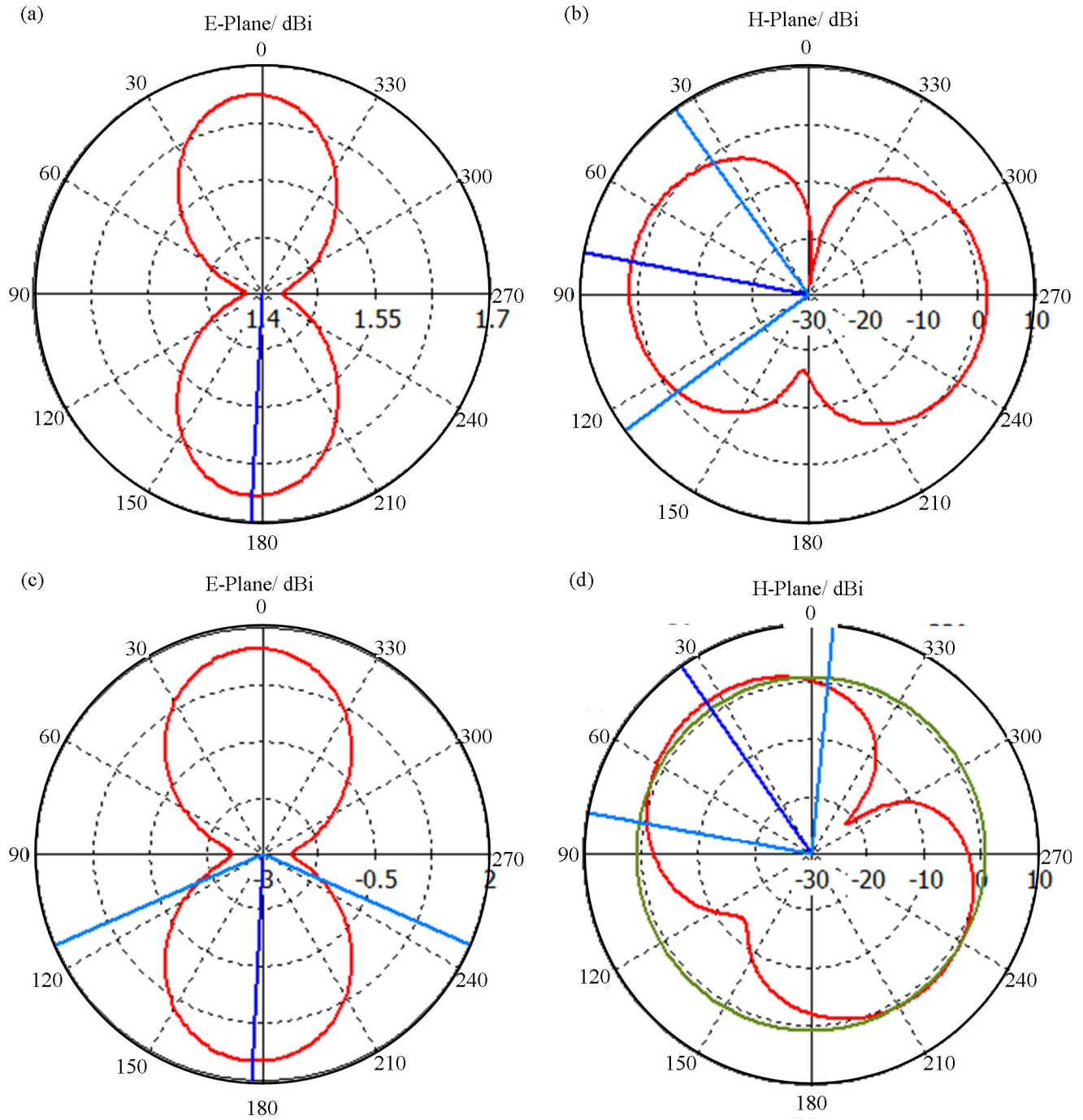


Fig. 3; Far field radiation patterns: (a) E-plane at $\Theta = 90^\circ$ and (b) H-plane at $\Phi = 90^\circ$ for 1.2 GHz.
(c) E-plane at $\Theta = 90^\circ$ and (d) H-plane at $\Phi = 90^\circ$ for 1.6 GHz.

B- Antenna Performance based on Array Structure

In this section, the antenna array performance is investigated by switching the patches of the single sector elements sequentially in their array structure. As seen in Fig. 4, the S-parameters in terms of S_{11} , S_{12} , and S_{13} are displayed by switching the antenna branches. It is found from switching the all patches on, the antenna shows three modes at 1.18 GHz, 1.62 GHz, and 1.82 GHz as seen in Fig. 4(a). However, by switching OFF patch II, two modes appear at 1.23 GHz and 1.83 GHz. After switching only the third patch ON, the antenna shows a mode at 1.23 GHz and the second mode is appeared due to the second harmonic generation.

In Fig. 4(b), the coupling effects between the sector 1 and sector 2 is presented. When three antenna branches are switched on, the antenna array shows the minimum coupling at 1.18 GHz, while, it shows higher coupling at 1.23 GHz and 1.82 GHz. By switching on the big and small branches on, the antenna provides -10 dB at 1.23 and 1.83 GHz. Now, after switching the big branch on, the antenna presents about -9 dB at 1.23 GHz. The coupling effects between the sector 1 and sector 3 is performed in Fig. 4(c). A higher coupling is found to be when three antenna branches are on at 1.18 GHz, 1.23 GHz, and 1.82 GHz. When the big and small branches are switched on, about the same coupling effect is obtained between sector 1 and sector 2 in Fig. 4(b). The lower coupling effect is achieved by switching only the big branch on at 1.23 GHz.

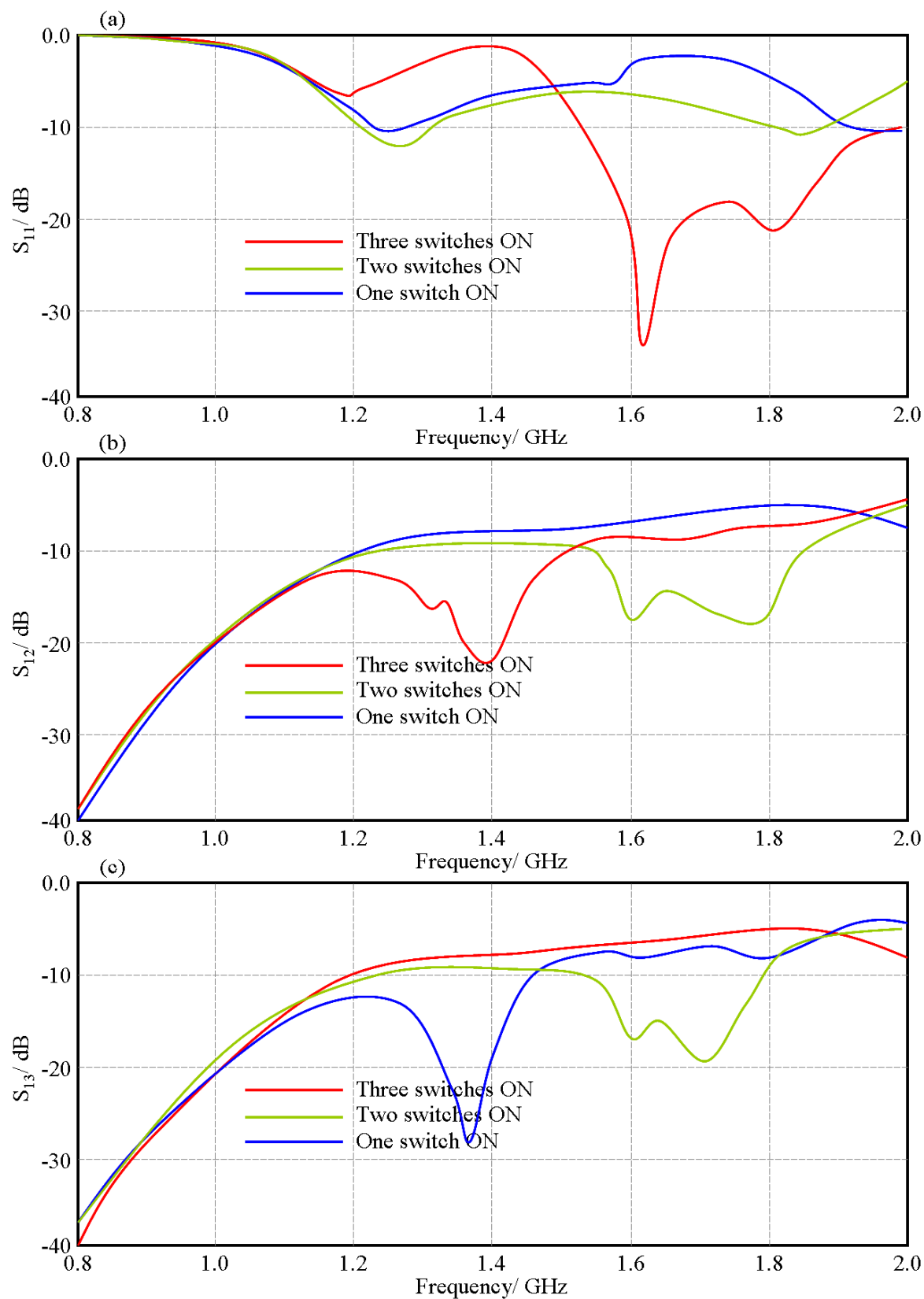


Fig. 4; S-parameters spectra: (a) S_{11} , (b) S_{12} , and (c) S_{13} .

For a MIMO system, the two adjacent antenna elements, the envelope correlation between the antenna elements is given by [12]

$$\rho_e = \frac{|S_{ii}^* S_{ij} + S_{ji}^* S_{jj}|^2}{[1 - (|S_{ii}|^2 + |S_{ji}|^2)][1 - (|S_{jj}|^2 + |S_{ij}|^2)]} \quad (1)$$

where i and j are for the first and the second antenna elements, respectively. The correlation envelop is evaluated between the first element with the second element and the first element with third element in terms of S_{12} and S_{13} , respectively as seen in Fig. 5.

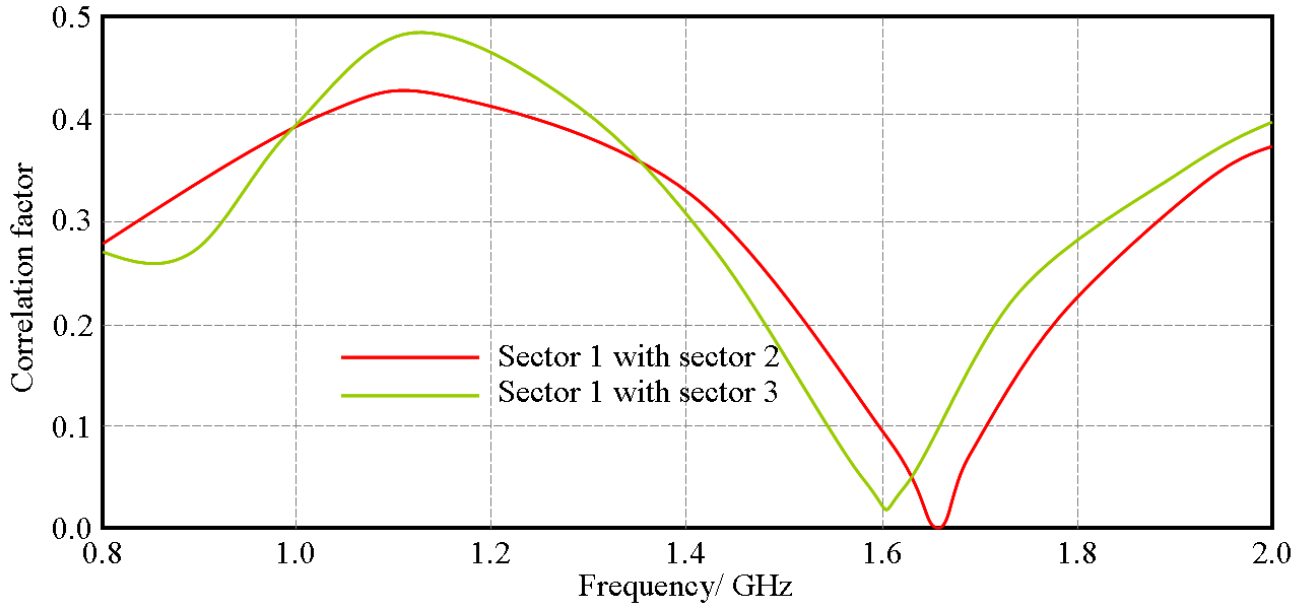
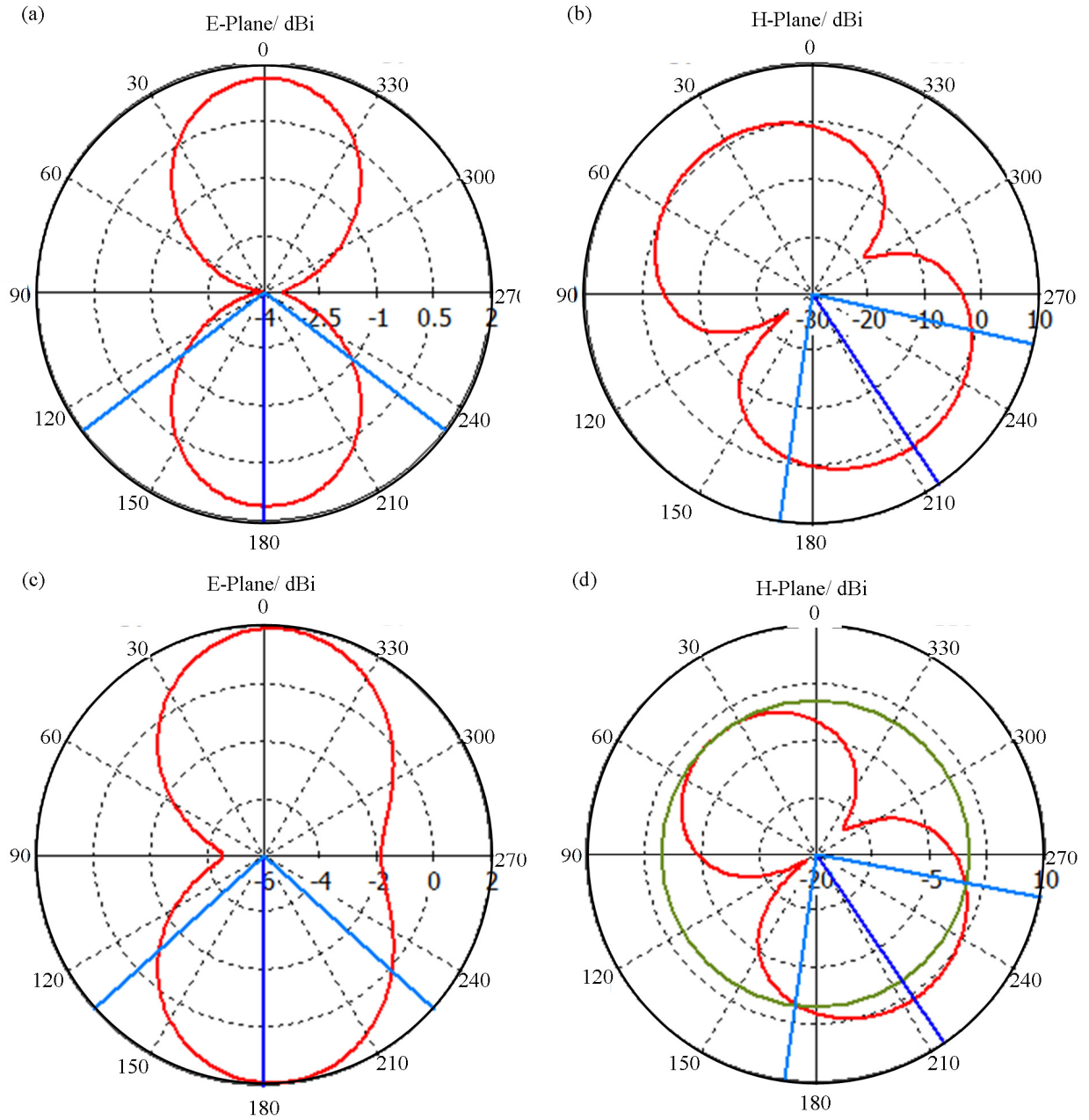


Fig. 4; Correlation profile between sector 2 and 3 with respect to sector 1.

In Fig.s 6, the radiation patterns in the E - (Theta=90) and H - (Phi=90) planes are displayed at 1.2 GHz and 1.6 GHz when the three switches are ON. The values of the antenna gain, beam width, main lobe direction are listed in Table 2.



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108 **Fig. 6;** Far field radiation patterns: (a) E-plane at $\Theta = 90^\circ$ and (b) H-plane at $\Phi = 90^\circ$ for 1.2 GHz.

109 (c) E-plane at $\Theta = 90^\circ$ and (D) H-plane at $\Phi = 90^\circ$ for 1.6 GHz.

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Table 2: Antenna array performance.

VALUES				
Performance	1.2 GHz	Sector 1	Main lobe magnitude	1.8 dB
		Sector 2	Main lobe direction	214.0°
			Beam Width	86.5°
	1.6 GHz	Sector 3	Main lobe magnitude	1.8 dB
			Main lobe direction	336.0°
		Sector 1	Beam Width	86.4°
			Main lobe magnitude	2.0 dB
		Sector 2	Main lobe direction	95.0°
			Beam Width	85.0°
	1.6 GHz	Sector 3	Main lobe magnitude	2.9 dB
			Main lobe direction	214.0°
		Sector 1	Beam Width	87.5°
			Main lobe magnitude	2.9 dB
		Sector 2	Main lobe direction	335.0°
			Beam Width	87.4°
	1.6 GHz	Sector 3	Main lobe magnitude	2.8 dB
			Main lobe direction	96.0°
		Sector 1	Beam Width	87.8°

IV. CONCLUSION

The eliminating of frequency reuse principle in the mobile Ad Hoc system using MIMO antenna array among the sectors of the unit cell is inspected in this paper. To realize this achievement, an antenna array of size of $10 \times 10 \text{ cm}^2$ is considered with using high diversity among antenna sectors. The single antenna sector is constructed from three patches that are connected to feeding transmission network through pin diodes, as switches, that are erected on an FR-4 substrate. Each single element of

the antenna differentiated in the space with 120° rotationally. The antenna performance is characterized from 0.8 GHz to 2 GHz in terms of *S*-parameters and radiation patterns with different switching OFF/ON strategies. It is found that the antenna low correlation factor and end fire radiation at the main lobe direction around 1.2 GHz and 1.5 GHz. A numerical investigation based on FIT is conducted using CST MWS to evaluate the antenna performance.

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