Simulation study of Four Element MIMO Antenna System with Pattern and Polarization Diversity

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ABSTRACT: In this paper, two configurations of previous work are extensively studied, namely pattern diversity and hybrid (pattern and polarization) diversity configuration. The first configuration provides the pattern diversity whereas second configuration provides both the pattern as well as the polarization diversity which helps to mitigate the multipath propagation effect. Both the configurations are designed over a small ground plane of size 100 × 60 × 0.8 mm^3. The isolations between antenna elements for both the configurations are better than -12 dB. The performances of both configurations are evaluated through *S*-parameters and radiation patterns. The diversity parameters namely, envelope correlation coefficient (ECC) and mean effective gain (MEG) are also studied.

Keywords— ECC, MEG, pattern diversity, PIFA, polarization diversity.

I. INTRODUCTION

Modern wireless communications have been a part of human life where people can communicate any time anywhere in the world with very high speed. In such scenario the multiple input multiple output (MIMO) made a great breakthrough by satisfying the demand of high speed with better quality mobile communication services without using any additional radio resources [1, 2]. In a MIMO wireless communication system, the transmitting end as well as the receiving end has to be equipped with multiple antenna elements to mitigate the multipath propagation effect. With multiple antenna elements at transmitter and receiver the higher channel capacity can be achieved by utilizing spatial and polarization diversity.

Various multi-element antennas have been considered and studied extensively [3-5]. A tri-band four element MIMO antenna has been reported, in which antenna elements are placed on each corner of the PCB [3]. The defected ground plane is used to achieve high isolation between antenna elements. It creates difficulties for RF circuits to feed the antenna elements when the solid ground plane is modified or removed. In [4], four similar compact dual-band chip antennas have been studied for WLAN access point devices. The reported antenna unable to covered the most demanding frequency bands like GPS L1 and long term evolution (LTE) which is standardized by 3rd generation partnership project (3GPP) in order to satisfy the market demand. Recently, a miniaturized four element diversity PIFA has been proposed for WLAN application [5], which follow the pattern diversity as well as exploits hybrid such as pattern and polarization diversity. But the isolation between two nearest antennas is less than -10 dB and also antenna operating over single frequency band i.e. WLAN. In [6], a multi antenna system with four printed monopoles is presented for UMTS frequency band only. Chiu *et al.* has been proposed compact four port antenna suitable for MIMO devices and operating at 2.48 GHz frequency [7]. A compact planar MIMO antenna system of four elements with similar radiation characteristics is proposed for the 2.4 GHz WLAN band [8]. Unfortunately, the above reported antennas [6-8] are operating over single frequency bands as well as size of the antennas remaining problematic.

In this paper, two configurations of a four elements quad band MIMO antenna system are studied. The single antenna element used in this study is taken from previous work [9]. In [9], a compact quad-band antenna array consisting of two PIFA elements for MIMO application has been presented, in which GPS band is accommodated with the other mobile communication bands. Here, we study the two Configurations of [9]. The first configuration exhibit pattern diversity and second configuration exploits hybrid pattern and polarization diversity. In each configuration, four antenna elements are placed over the PCB. Diversity performances characteristics like ECC and MEG for both the configurations are calculated and also radiation patterns are shown, which confirms the pattern and polarization diversity of the configurations.

II. ANTENNA CONFIGURATION

A. *Single-Element PIFA*

The dimension of single antenna element of reported MIMO antenna in [9] occupies a volume of 25 × 10 × 5.8 mm^3 above the mobile circuit board and is suitable to fabricated at low cost and is attractive for slim mobile phones. The detail dimensions of single antenna element and performances investigation of the quad band MIMO antenna has been elaborated in [9]. The geometry of antenna, *S*-parameters response, and radiation patterns of the reportedPIFA is suitable for GPS L1, Wi-Fi, LTE2500, WiMAX, and HIPERLAN applications, further radiation patterns of antenna show almost omni-directional pattern.

B. *Multi-Element PIFA Configurations*

After finalize the single antenna element and its MIMO configuration with two elements, we need to place the other elements in such a way to maximize the diversity performances and channel capacity. In view of this we are tried to design two configurations with varying orientation shown in Fig. 2. In Config. 1, all the antenna elements are mirror image of each other, whereas in Config. 2, the Ant. 2 is placed orthogonally with respect to Ant. 1 while Ant. 3 is also orthogonally placed with respect to the Ant. 4. The cross-polarized antenna orientation gives the extra polarization diversity in addition to pattern diversity.

III. **RESULTS AND DISCUSSION**

All the simulations are carried out using CST MWS which is based on finite integration techniques (FIT) [10] and all diversity parameters of the proposed two configurations are evaluated using CST MWS.

A. S-parameters Analysis

The simulated *S*-parameters for the proposed two configurations are shown in Fig. 3. The reflection coefficient and coupling coefficient of Config. 1 is shown in Fig. 3(a). It is observed that antenna covers the GPS L1 (1.565– 1.585 GHz), Bluetooth/Wi-Fi (2.4–2.484 GHz), LTE2500 (2.5–2.57 GHz for uplink, 2.62–2.69 GHz for downlink), WiMAX (3.3–3.4 GHz), and HIPERLAN (5.15–5.35 GHz). Due to the symmetric placement of antenna over PCB (mobile circuit board) the reflection coefficient of Ant. 1, Ant. 2, Ant. 3, and Ant. 4 are same for Config. 1. The mutual coupling between antenna elements for this Configuration is below -12 dB. In the Config. 2, Ant. 1 & Ant. 2 and Ant. 3 & Ant. 4 are placed orthogonally to each other on the PCB. The *S*-parameters of the Config. 2 are shown in Fig. 3(b). It is observed that reflection coefficient of Ant. 1 and Ant. 4 is same due to symmetrical placement of antenna over the PCB whereas reflection coefficients of Ant. 2 and Ant. 3 show small deviation but still cover the desired operating frequency bands and achieved isolation between antenna elements is well below -12 dB.

B. Radiation Patterns

The simulated 3D total far-field radiation patterns of two different configurations at four different resonating frequencies are shown in Fig. 4. In the case of MIMO antenna system only one port is excited while keeping other port is matched terminated with 50 Ω load. In the config. 1 each element is mirror image to each other due to which radiation patterns of antenna elements are complimentary in space that shows the pattern diversity which helps to mitigate the multipath propagation effects. In the Config. 2, the cross-polarized antenna orientation gives the extra polarization diversity in addition to pattern diversity. It is noted that the radiation patterns of pair Ant. 1 & Ant. 2 are orthogonal due to perpendicular placement of antenna elements to each other and same pattern of pair Ant. 3 & Ant. 4 is observed, simultaneously the radiation patterns of pair Ant. 1 & Ant. 4 are complimentary to each other that exhibits the pattern diversity and similar patterns for pair Ant. 2 & Ant. 3 is observed.

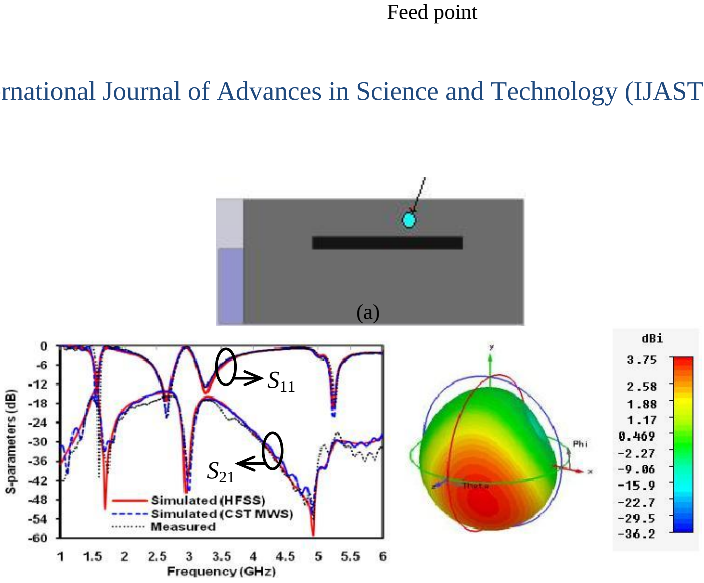


Fig. 1 (a) Single antenna element of [9], (b) *S*-parameters and radiation pattern of single antenna elements

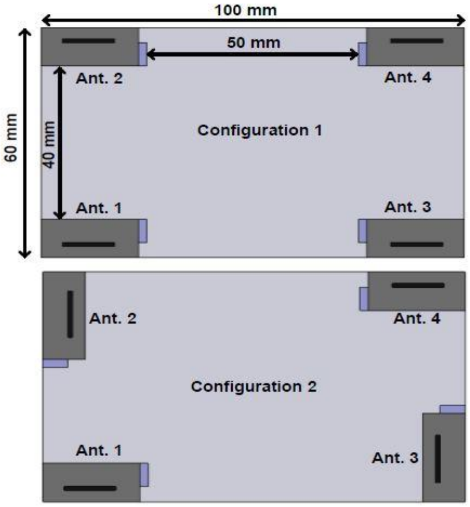
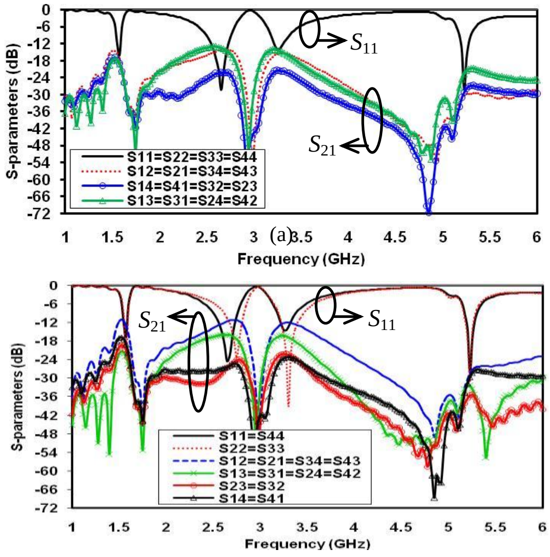


Fig. 2 Orientation of antenna elements



(b)

Fig. 3 (a) *S*-parameters of Config. 1 (b) *S*-parameters of Config. 2

IV. DIVERSITY PERFORMANCES

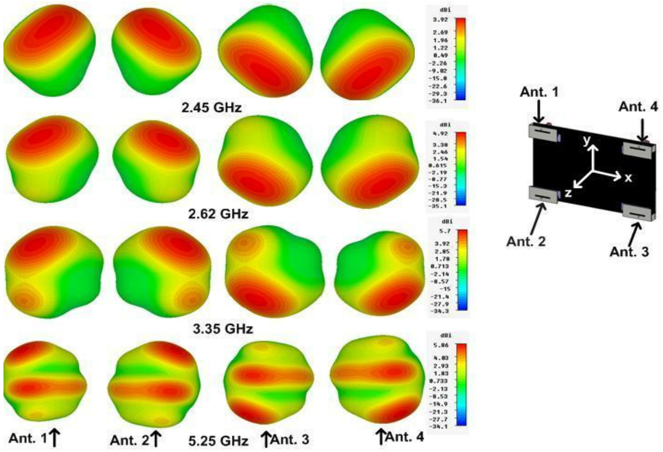
A. ECC

For calculation of ECC, we can approach either *S*-parameters approach or far field pattern data methods. In *S*-parameters approach the ECC is evaluated using *S*-parameters of the MIMO system, reported in reference [11] under the following assumptions. i) the antenna system is a lossless structure, ii) one antenna is excited while the other is terminated with a reference impedance (such as 50Ω); and iii) the antenna system is in a uniform scattering environment.

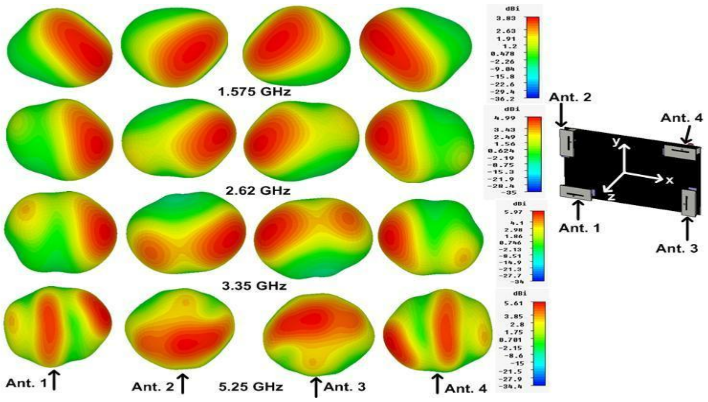
The calculation of ECC with *S*-parameters is valid for ideal antenna cases but practically the mobile terminal antenna's efficiency is not ideal in multipath propagation environment. Therefore, it is not possible to satisfy the i) and iii) assumptions. So here we are going with far field pattern approach [12], in which the ECC (ρ_e) given in terms of complex cross correlation (ρ_c)

$$\rho_e = |\rho_c|^2 \qquad (1)$$

The complex cross correlation ρ_c is evaluated using radiation pattern given in [1],



(a)



(b)

Fig. 4 Simulated 3D total far-field radiation patterns of (a) Config. 1 (b) Config. 2

$$\rho_c = \frac{\int_0^{2\pi}\int_0^{\pi} A_{12}(\theta,\phi)\sin\theta d\theta d\phi}{\sqrt{\int_0^{2\pi}\int_0^{\pi} A_{11}(\theta,\phi)\sin\theta d\theta d\phi}\sqrt{\int_0^{2\pi}\int_0^{\pi} A_{22}(\theta,\phi)\sin\theta d\theta d\phi}} \qquad (2)$$

$$A_{ij} = XPR\cdot E_{\theta,i}(\theta,\phi)E^{*}_{\theta,j}(\theta,\phi)P_{\theta}(\theta,\phi) + E_{\phi,i}(\theta,\phi)E^{*}_{\phi,j}(\theta,\phi)P_{\phi}(\theta,\phi) \qquad (3)$$

where, $E_{\theta,\phi}(\theta,\phi)$ and $P_{\theta,\phi}(\theta,\phi)$ are respectively the complex electric field and power angular density function of the incoming plane waves in the θ- and ϕ- polarizations. *XPR* is the vertical to horizontal time average power ratio. Where *i*, *j*=1, 2, 3, 4 and $i \neq j$. The calculated average values of ECC are given in Table I for two different configurations. It is interestingly noted that multi element antenna (MEA) configurations (Config. 2) having very low correlations due to their pattern and polarization diversity.

B. MEG

In the multi path propagation environment, MEG defined as the ratio between the mean received power of antennas over a random route and the total mean incident power at the antenna elements [12],

$$MEG = \int_0^{2\pi}\int_0^{\pi} \frac{XPR\cdot G_{\theta i}(\theta,\phi)P_{\theta}(\theta,\phi) + G_{\phi i}(\theta,\phi)P_{\phi}(\theta,\phi)}{1+XPR}\sin\theta d\theta d\phi \qquad (4)$$

where, *XPR* represents the cross-polarization ratio, G_θ and G_ϕ are the power gain patterns, and P_θ and P_ϕ are the θ - and ϕ-components of angular density functions of the incident power, respectively. Where *i*,*j*=1,2,3,4 and $i \neq j$.

The distributions of the angular density functions are depend on the surrounding environment. Some sample statistical models and their typical parameter values for indoor, outdoor, and isotropic environments have been discussed for the angular density function in [13]. In this paper, P_θ and P_ϕ are assumed to be Gaussian in elevation and uniform in azimuth, and are given by,

$$P_{\theta}(\theta,\phi) = A_{\theta}\exp\left[\frac{-\left\{\theta-\left(\frac{\pi}{2}-m_V\right)\right\}^2}{2\sigma_V^2}\right], (0 \le \theta \le \pi) \qquad (5)$$

$$P_{\phi}(\theta,\phi) = A_{\phi}\exp\left[\frac{-\left\{\theta-\left(\frac{\pi}{2}-m_H\right)\right\}^2}{2\sigma_H^2}\right], (0 \le \theta \le \pi) \qquad (6)$$

where, m_V, m_H are the mean elevation angles of θ- and ϕ-

component wave distribution observed respectively, σ_V and σ_H are the standard deviations of θ- and ϕ- component wave distributions respectively. A_θ and A_ϕ are constants and determined by,

$$\int_0^{2\pi}\int_0^{\pi} P_\theta(\theta,\phi)\sin\theta d\theta d\phi = \int_0^{2\pi}\int_0^{\pi} P_\phi(\theta,\phi)\sin\theta d\theta d\phi = 1$$

(7)

Table II gives the computed MEG for different *XPR* at different frequency bands by setting the, $m_V=10^0$, $m_H=10^0$, $\sigma_V=15^0$, and $\sigma_H=15^0$ as given condition in [14]. From the table, it can be noticed that the received signals satisfy the condition $\rho_{e\,i,j} < 0.5$ and $P_i = P_j$ $\left|MEG_i - MEG_j\right| < 3\text{dB}$; $i, j = 1, 2, 3, 4$; $i \neq j$.

Table 1
Average ECC Values of Multi Element Antenna Configuration

Freq. → ↓ **Type**	**1.575 GHz**	**2.62 GHz**	**3.35 GHz**	**5.25 GHz**
Config.1	0.120	0.0104	0.036	0.019
Config.2	0.061	0.013	0.019	0.008

Table 2
Values Of Meg for Two Configurations

Config.	**Environment**	**Antenna MEGs (dB)**	**1.575 GHz**	**2.62 GHz**	**3.35 GHz**	**5.25 GHz**
Configuration 1	Isotropic MEG=0dB	MEG 1	-9.07	-5.12	-4.70	-7.3
		MEG 2	-9.07	-5.12	-4.65	-7.3
		MEG 3	-9.07	-5.12	-4.66	-7.3
		MEG 4	-9.07	-5.12	-4.65	-7.3
	Indoor MEG=1dB	MEG 1	-9.33	-5.12	-4.65	-7.3
		MEG 2	-9.34	-5.12	-4.65	-7.28
		MEG 3	-9.33	-5.12	-4.65	-7.28
		MEG 4	-9.34	-5.12	-4.65	-7.3
	Outdoor MEG=5dB	MEG 1	-10.4	-5.55	-4.60	-7.23
		MEG 2	-10.4	-5.55	-4.61	-7.22
		MEG 3	-10.4	-5.55	-4.60	-7.22
		MEG 4	-10.4	-5.55	-4.61	-7.23
Configuration 2	Isotropic MEG=0dB	MEG 1	-8.86	-5.00	-4.54	-7.17
		MEG 2	-9.24	-5.23	-4.52	-7.88
		MEG 3	-9.25	-5.24	-4.52	-7.85
		MEG 4	-9.87	-4.94	-4.53	-7.16
	Indoor MEG=1dB	MEG 1	-9.13	-5.04	-4.54	-7.16
		MEG 2	-9.48	-5.35	-4.5	-7.9
		MEG 3	-9.49	-5.35	-4.7	-7.87
		MEG 4	-9.15	-5.04	-4.54	-7.15
	Outdoor MEG=5dB	MEG 1	-10.2	-5.40	-4.50	-7.13
		MEG 2	-10.4	-5.74	4.30	-7.95
		MEG 3	-10.4	-5.74	-4.31	-7.93
		MEG 4	-10.3	-5.40	-4.50	-7.12

V. CONCLUSIONS

In this paper, two configurations of four antenna elements array have been extensively studied. Both the configurations are suitable for GPS L1, Wi-Fi, LTE2500, WiMAX, and HIPERLAN applications, further mutual coupling between antenna elements is better than -12 dB for both the configurations. The Config. 1 show pattern diversity whereas Config. 2 show hybrid i.e. pattern and polarization diversity. Both the MEA configuration provides extremely low correlations due to pattern and polarization diversity. The MEGs across all the elements is nearly equal. These two factors lead to very good diversity performances.

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