A High Isolation 4 by 4 MIMO Antenna for LTE Mobile Phones using Coupling Elements

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Abstract

In this paper, we develop a simple but very effective 4 by 4 Multiple-Input Multiple-Output (MIMO) antenna system for mobile phones consisting of different types of antennas to achieve low correlation property at the frequency ranges of 1710 to 2170 MHz, which covers wide LTE service bands, from band 1 to band 4. The proposed antenna system consists of two pair of antennas. Each pair consists of a planar inverted-F antenna (PIFA) and a coupling antenna which has the property of the loop. The use of two different antenna types of IFA and a coupling achieves high isolation. Proposed antenna system occupies relatively small area and positions at the four corners of a printed circuit board. The gap between the two antennas is 4 mm, in order to realize the good isolation performance. To evaluate the performance of our proposed antenna system, we perform various experiments. The proposed antenna shows a wide operating bandwidth greater than 460 MHz with isolation between the feeding ports higher than 17.5-dB. It also shows that the proposed antenna has low Envelop Correlation Coefficient (ECC) values smaller than 0.08 over the all desired frequency tuning ranges.

Keywords: Antenna, ECC, Isolation, LTE, MIMO

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1. Introduction

The rapid growth of Long Term Evolution (LTE) mobile subscribers has led a drastic increase of demands for larger data capacity of radio links [1-3]. The number of antennas should increase to support 4x4 MIMO. It will be a great challenge for device manufactures to put two additional antennas for 4x4 MIMO into smartphones with the small-size design.

The downlink data throughput of LTE mobile devices on the radio channel environment mainly depends on MIMO channel estimator performance of the communication modem chip, which is closely related to the characteristics of the antenna correlation. However, there are many technical challenges in implementing mobile antennas that show low correlation properties and sufficient antenna gains in mobile stations [4]. If the isolation within the multi-antenna system is insufficient, the performance of the system is reduced in terms of the gain and the correlation because of the coupling effect between antennas.

There have been many previous studies on reducing the correlation property of the mobile antenna [5-7]. [5] show that the antenna correlation can be reduced by T-shaped decoupling structure between the radiators. [6] reduces the coupling effect between MIMO antenna elements integrating a E-shaped patch and two small size slots. [7] reduces the correlation by adding an isolation element formed to a protruded ground plane between antennas. This paper introduces a 4 by 4 antenna system with high isolation designed for mobile stations using only different type of antennas rather than using other isolated elements as in [5-7]; therefore our proposed antenna system is smaller and more flexible for MIMO antenna design than previous antenna solutions.

To determine the performance of our proposed antenna system, we perform various and through experiments, which show that our antenna system is good in terms of S-parameter, Gain, ECC and 3D radiation pattern.

2. Antenna Design

In this section, we present the design of our proposed antenna system for 4 by 4 MIMO and its potential improvement via simulations. The basic idea of the proposed antenna system is to use different antenna types rather than the same antenna type for MIMO antenna. It consists of a PIFA and a coupling antenna which has the property of the loop. A coupled element is used as the signal feed port (port 2 and port 4) of first type antenna which forms semi-loop antenna with the branch from ground short. A good isolation between the IFA branch and the coupling antenna branch can be achieved because the resonance mode of IFA is transverse electric (TE) and that of coupling antenna is transverse magnetic (TM) mode and thereby the two resonance modes are orthogonal to each other. 4 by 4 MIMO antennas have four receiver path and one transmitter path. One of the four antennas has transmitter path and receiver path, and the other three of the four antennas have only receiver path.

Fig. 1 shows the prototype of our proposed 4 by 4 MIMO antenna system. It consists of two pair of antennas, and each pair consists of a PIFA and a coupling antenna, that is, different types of antennas. 50 ohm-shielded semi-rigid cables with SMA connectors are launched to the signal feed point of each antenna. We design the antenna system for a typical smartphone with an area of 60 mm × 130 mm^2, which is manufactured on the top of a FR4 substrate PCB that is usually used for practical mobile handsets.

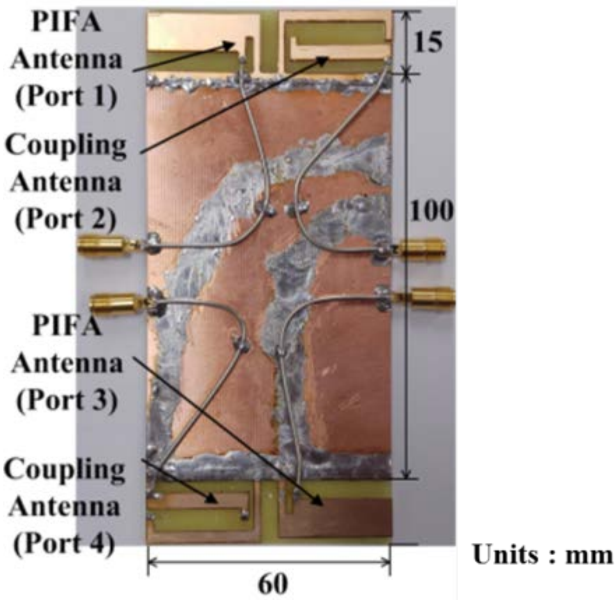
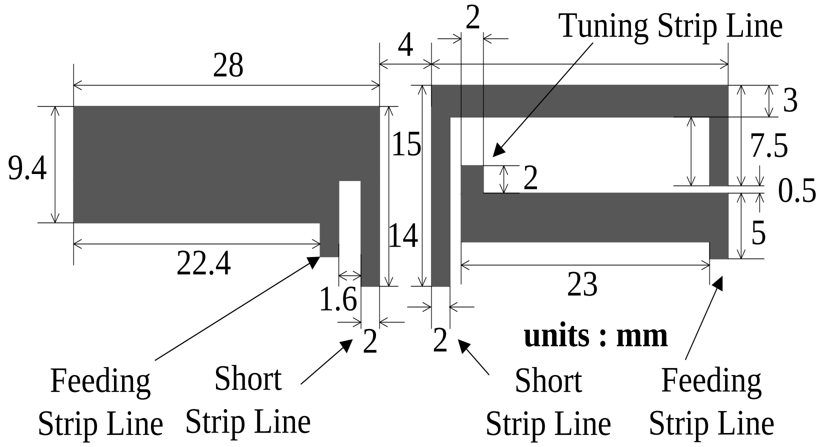


Fig. 1. Photography of proposed MIMO antennas

To see the effectiveness of our proposed antenna system, we perform simulations for the S-parameter and the current flow. We manufacture two dual antennas. One consists of a PIFA and a coupling antenna. The other consists of two PIFA. **Fig. 2** shows geometries of dual antennas manufactured for the simulation. **Fig. 2(a)** is the former, and **Fig. 2(b)** is the latter.



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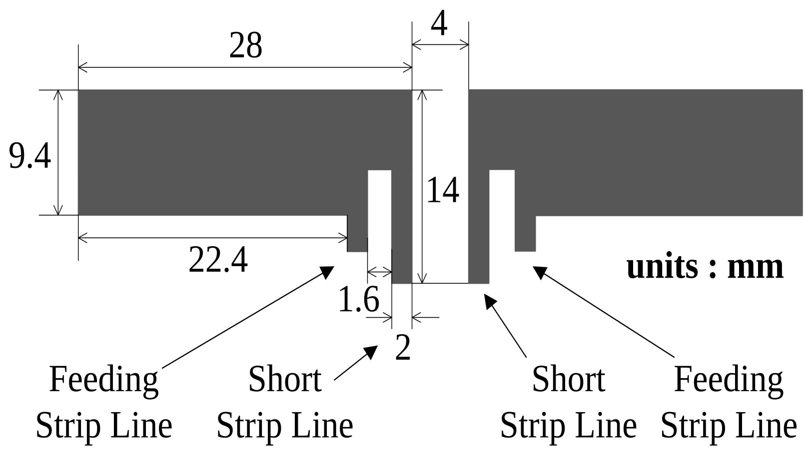
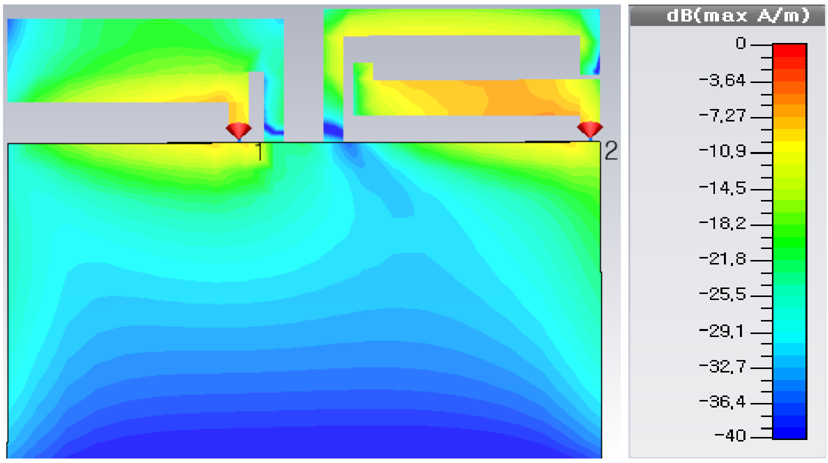


(b)

Fig.2. Geometry of the proposed antenna.
(a) Proposed PIFA vs Coupling antenna, (b) PIFA vs PIFA antenna.

To show the reason why PIFA vs Coupling is better than PIFA vs PIFA, we perform the antenna simulation for the current flow distributions across PCB with the two antenna. We use Computer Simulation Technology (CST) (MICROWAVE STUDIO 2011) for the simulation [8]. Current null area exists between the two ports, and it produces high port-to-port isolation.

Fig. 3 shows the current distributions for the proposed antenna at 1.84 GHz and 2.14 GHz with both ports simultaneously excited. It is observed in **Fig. 3 (a)** and **(c)** that the surface current between two ports is not highly concentrated when two ports are excited. Therefore good port to port isolation characteristics are expected. But **Fig. 3 (b)** and **(d)** show the poor performance of the port-to-port isolation for PIFA vs PIFA because of current null area doesn't exists between the two ports.



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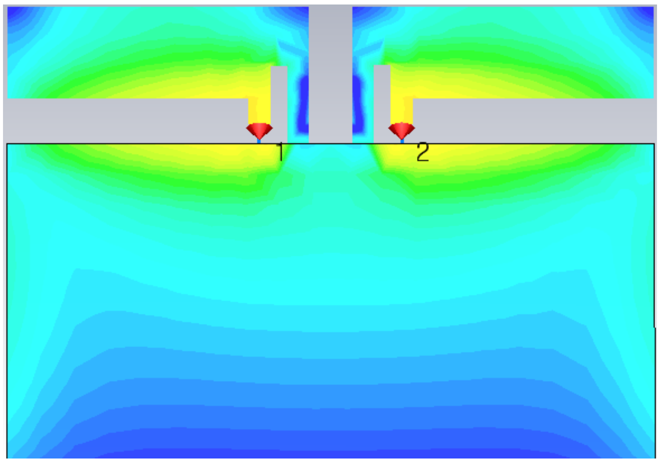

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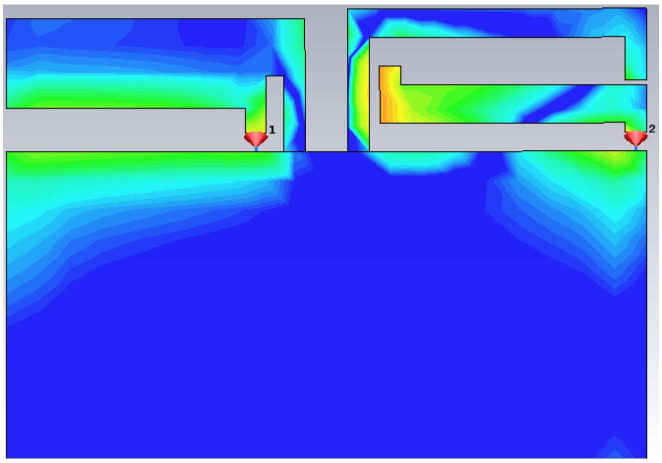

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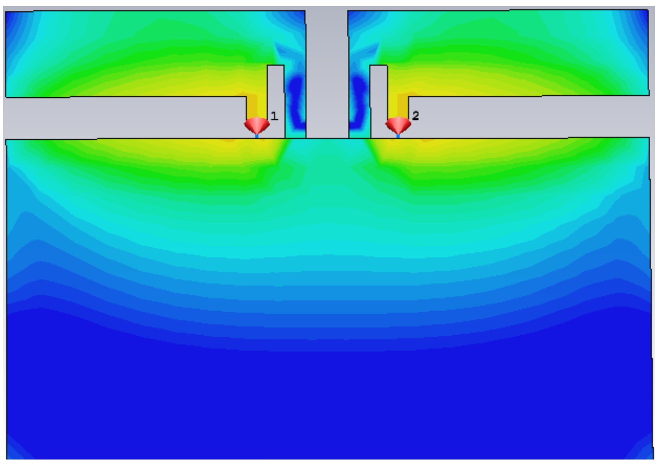
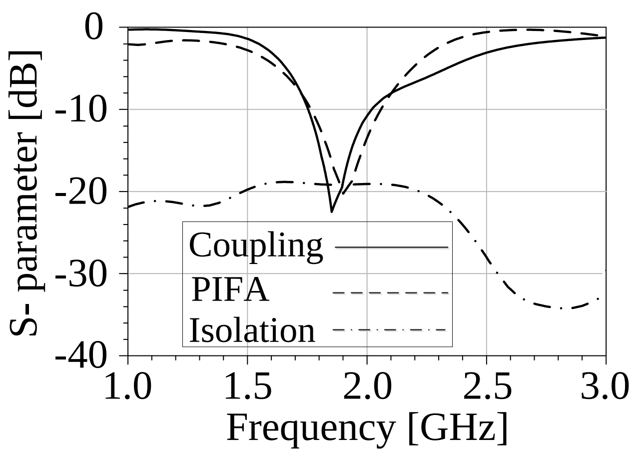


(d)

Fig. 3. Simulated current distributions. (a) Proposed PIFA vs Coupling antenna at 1.84 GHz, (b) PIFA vs PIFA antenna at 1.84 GHz, (c) Proposed PIFA vs Coupling antenna at 2.14 GHz, (b) PIFA vs PIFA antenna at 2.14 GHz

Fig. 4 shows simulation results for the return loss and the isolation. It shows that both two antenna systems are well matched for the desired frequency, but PIFA vs Coupling antenna system is better than PIFA vs PIFA antenna system by 9dB in terms of the isolation. That is, we can say that our proposed antenna system shows excellent isolation characteristics compared to the existing antenna system using same type of antennas.



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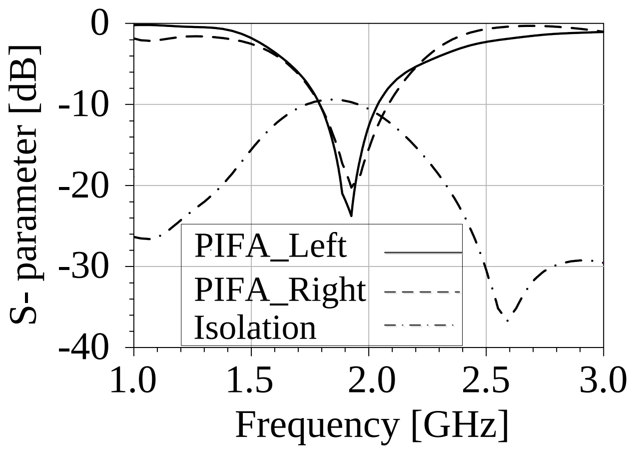


(b)

Fig. 4. The simulation results for S-parameter (a) Proposed PIFA vs Coupling antenna, (b) PIFA vs PIFA antenna.

3. Antenna Performances

We perform through and various experiments to evaluate our proposed 4 by 4 antenna system using the prototype as shown in **Fig. 1**. We evaluate the performance of our proposed system in terms of four traditional evaluations metrics: S-parameter, Gain, ECC and 3D radiation pattern. The desired LTE bands are from band 1 to band 4, frequency ranges of 1710 to 2170 MHz. We measure the performance of the prototype using E5071C, a vector network analyzer.

Fig. 5 and **Fig. 6** shows the measured and simulated return losses and isolations of the proposed antenna. **Fig. 5** presents the measurement result. It can be observed that the measured bandwidths (defined by Sii < -6 dB, i = 1,2,3,4) are 1.71 - 2.17 GHz. Both the Coupling and PIFA antennas are well matched over the desired frequency. The characteristic of the isolation are important in MIMO antennas due to the fact that it is directly related to the correlation properties of MIMO antennas. The configuration exhibits good isolation characteristics because the mutual coupling among antenna elements does not exceed -17.5 dB for all cases of Sij (i, j = 1,2,3,4; i ≠ j). Thus, antenna efficiency values can be maintained at a high level because they are less affected by the mutual coupling.

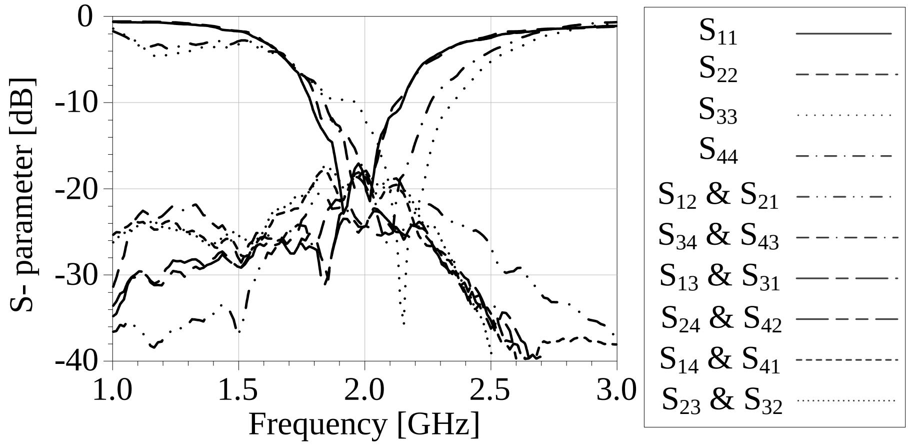


Fig. 5. Measured return loss characteristics for the proposed antenna

Fig. 6 shows the simulated S-parameter of the designed MIMO antennas. To optimize the geometric parameters of proposed antennas, we also use CSTs Microwave Studio, a commercial electromagnetic solver. The simulated return loss(Sii, i = 1,2,3,4) and isolation characteristics (Sij i, j = 1,2,3,4; i ≠ j) of the proposed antenna system are generally in agreement with the measured data as shown in **Fig. 5**. The slight difference is due to the effect of coherency and manufacturing tolerance.

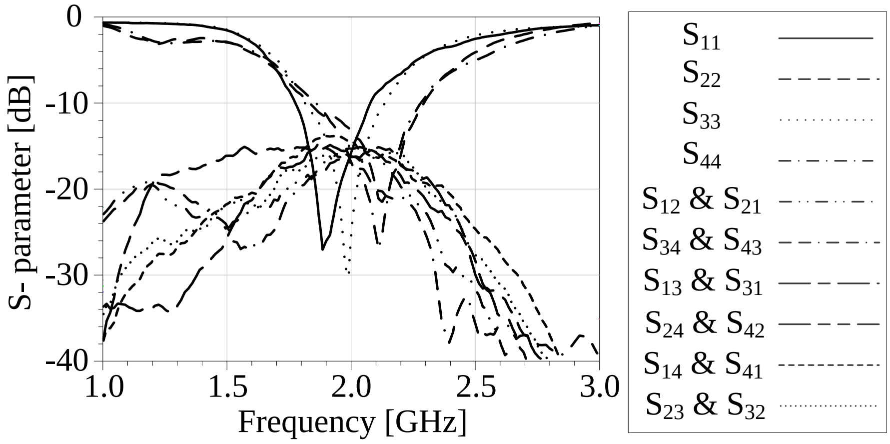


Fig. 6. Simulated return loss characteristics for the proposed antenna

Fig. 7 shows the measured average gain of our proposed antenna system. The measured average gain including the mismatching loss for port 1 of primary antenna is about -1.16 dBi to 0.49 dBi with the gain variation of 1.65 dB and for port 2 of primary antenna is about -1.98 dBi to 0.48 dBi with the gain variation of 2.46 dB. For port 3 of secondary antenna, the average gain is from -0.92 dBi to 0.34 dBi and the gain variation is less than 1.26 dB and for port 4 of secondary antenna is about -2.17 dBi to 0.41 dBi with the gain variation of 2.58 dB. The antenna efficiencies over the operating bands are reasonable for practical handset applications. We measure it using Microwave Technologies Group version 2.1 (MTG ver.2.1), a 3D measurement system [9].

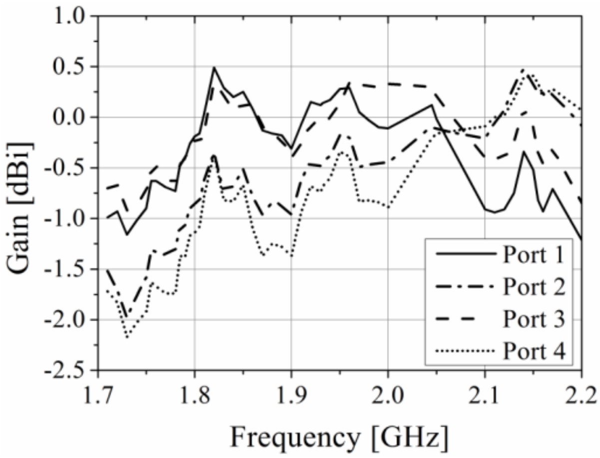


Fig.7. Measured average gain

Under the assumption of uniformly scattered radio environments, the ECC between the two antennas can be easily obtained from equation (1) by using measured far-field radiation patterns [10].

$$\rho_{12} = \frac{\left|\oint\{(XPR\cdot E_{\theta MA}(\Omega)\cdot E^{*}_{\theta SA}(\Omega) + E_{\emptyset MA}(\Omega)\cdot E^{*}_{\emptyset SA}(\Omega)\}d\Omega\right|^{2}}{\oint\{XPR\cdot G_{\theta MA}(\Omega)+G_{\emptyset MA}(\Omega)\}d\Omega\cdot\oint\{XPR\cdot G_{\theta SA}(\Omega)+G_{\emptyset SA}(\Omega)\}d\Omega} \quad (1)$$

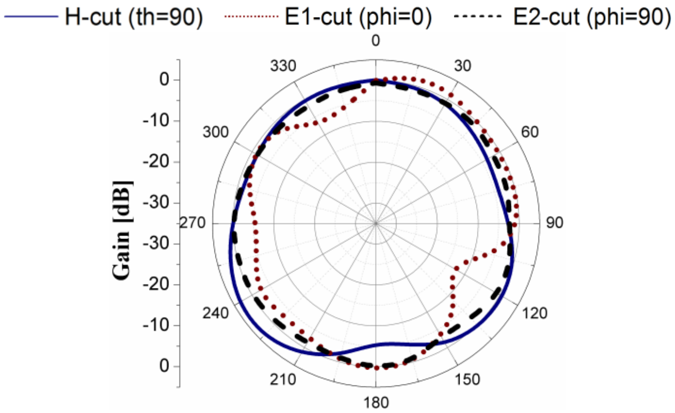
where $E_{\theta MA}(\Omega)$ is the vertical polarization complex radiation pattern from the main antenna, $E_{\theta SA}(\Omega)$ is the vertical polarization complex radiation pattern from the sub-antenna, $E_{\emptyset MA}(\Omega)$ is the horizontal polarization complex radiation pattern from the main antenna, $E_{\emptyset SA}(\Omega)$ is the horizontal polarization complex radiation pattern from the sub-antenna, and Ω is the solid angle for a spherical coordinate system. When XPR = 1, the test environment is isotropic.

In order to guarantee a reliable MIMO performance, ECC must be smaller than 0.5 [11]. The antenna needs to support wide tuning ranges of operating bands too. Table 1 summarizes the measured ECC value obtained from the fabricated antenna at each LTE band. ECC values for all considered bands are smaller than 0.08.

Table 1. Measured ECC characteristics for the proposed antenna

Antenna	PIFA1 vs Coup.1	PIFA2 vs Coup.2	PIFA1 vs PIFA2	Coup.1 vs Coup.1	PIFA 1 vs Coup.2	PIFA 2 vs Coup.1
Band 1, 4 (2.14GHz)	0.01	0.05	0.02	0.01	0.01	0.05
Band 2 (1.96GHz)	0.02	0.02	0.04	0.01	0.02	0.04
Band 3 (1.84GHz)	0.03	0.06	0.03	0.01	0.05	0.08

Fig. 8 shows the measured 3D radiation patterns for the main antenna in free space. The H (yz) plane patterns confirm that the antenna has nearly omnidirectional patterns in the operating bands.



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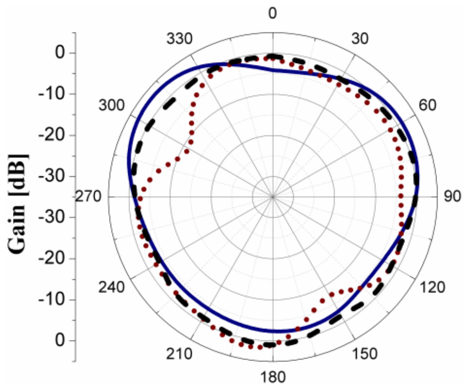

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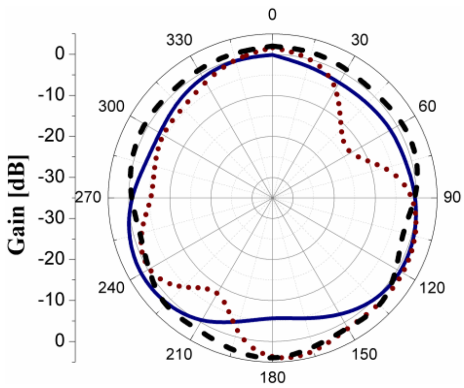

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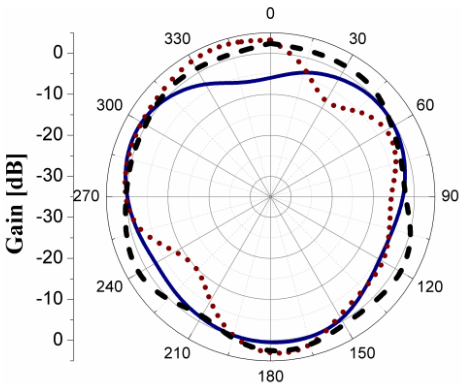
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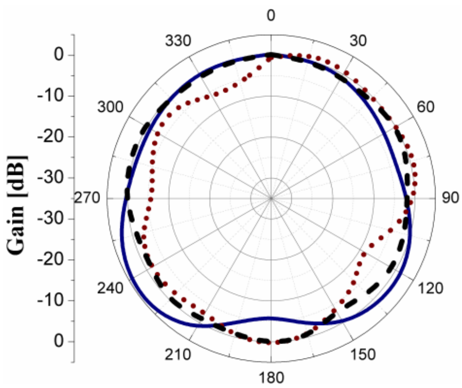
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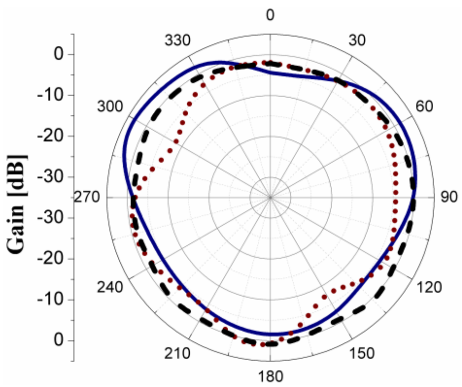
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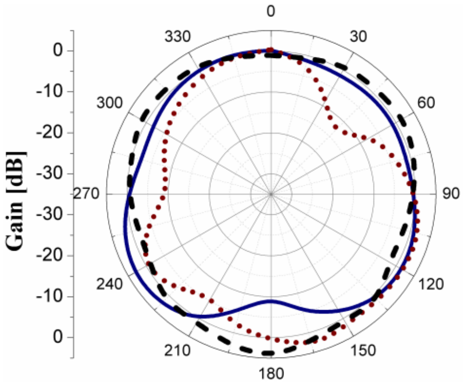
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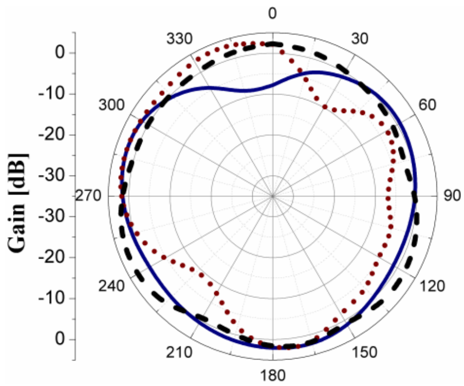
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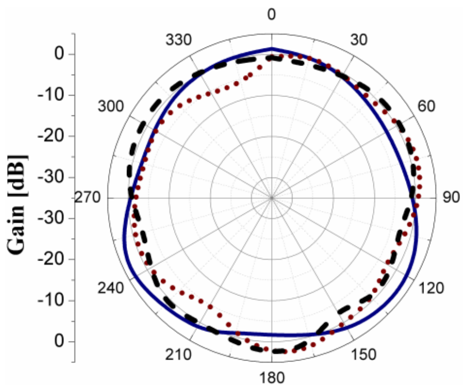
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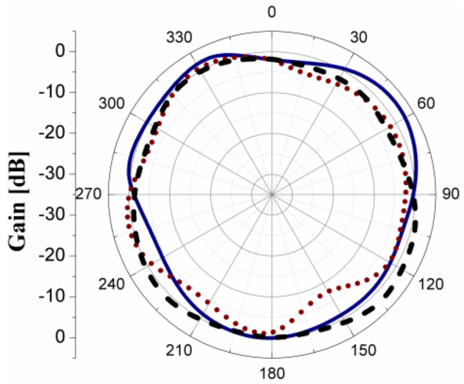

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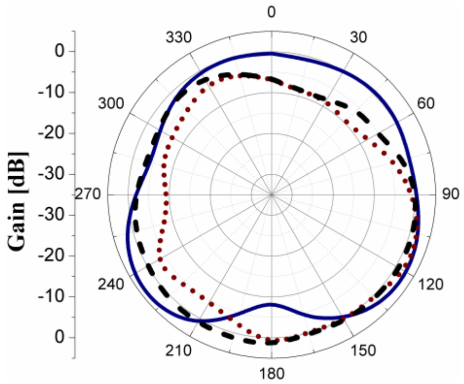

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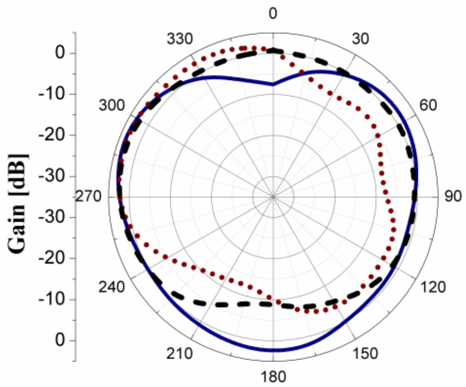

(l)

Fig. 8. Measured 3-D radiation patterns of the proposed antenna. (a) 1.84 GHz for port 2, (b) 1.84 GHz for port 4, (C) 1.84 GHz for port 1, (d) 1.84 GHz for port 3, (e) 1.96 GHz for port2, (f) 1.96 GHz for port 4, (g) 1.96 GHz for port 1, (h) 1.96 GHz for port 3, (i) 2.14 GHz for port 2, (j) 2.14 GHz for port 4, (k) 2.14 GHz for port 1, (l) 2.14 GHz for port 3.

4. Conclusion

This paper presents a novel 4 by 4 MIMO antenna system reducing the correlation between antennas, eventually enhancing the isolation without additional sticks. The proposed antenna system consists of two pairs of antennas. Each pair consists of a planar inverted-F antenna (PIFA) and a coupling antenna which has the property of the loop. We construct the prototype of the proposed antenna system and perform a variety of experiments. The desired LTE bands are from band 1 to band 4. The measured 6-dB impedance bandwidth of the prototype is 460 MHz with more than 17.5-dB isolation over the required bands. ECC values for all considered bands are smaller than 0.08. The experimental results show well that the proposed antenna system is useful and suitable for mobile phones. We believe that our experiments show well the effectiveness of our proposed antenna system.

Acknowledgements

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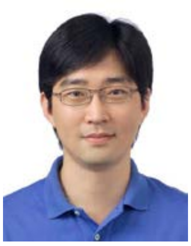

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