Four-Element Planar MIMO Antenna for Indoor Communications with High Isolation

Mohamed M. Morsy

Department of Electrical Engineering
Texas A&M University-Texarkana, Texarkana, TX 75503, USA
mmorsy@tamut.edu

Abstract ─ A low-profile monopole microstrip antennas with multiple-input-multiple-output (MIMO) configuration for a 4G/5G communication terminal is presented. The MIMO antenna system consists of four elements that operate in the LTE1800/2600 and GSM1800 bands. The antenna elements are mounted along the four sides of a rectangular ground plane of size 120×100 mm^2. Spatial diversity technique and a modified ground plane are used to enhance isolation between elements. To mitigate the mutual coupling effect, the lower corners of the ground plane have been truncated. The measured isolation is lower than -17 dB between any two elements over the operating frequency bands. The total efficiency ranges from 69% to 83% and from 73% to 86% over LTE1800 and LTE2600 bands, respectively. The diversity performance of the measured envelope correlation coefficient (ECC) and radiation patterns meet the diversity criteria for 4/5G networks.

Index Terms ─ LTE antenna, Microstrip antenna, MIMO antenna, Monopole antennas, Planar antenna

I. INTRODUCTION

The development of the long-term-evolution (LTE) technology has been an on-going process in the last decade. LTE satisfies the demand of the 4/5G networks that require high data capacity and speed. Because of the various band allocations of LTE in different countries, the design of LTE antennas mandates multiple frequency bands operation. Furthermore, MIMO is another major technology used to enhance the performance of LTE networks. Although MIMO technology adds to the complexity of LTE antenna design in terms of number of antennas, it provides high data rates and improved spectral efficiency. In order to have an efficient MIMO antenna system for user's devices, there are many challenges that have to be addressed. Among them is to design uncorrelated MIMO antenna elements in a confined space. Many techniques have been used to increase the isolation of MIMO elements while maintaining a compact design. The most common technique is to use the spatial diversity technique by separating antenna elements by 0.5 λ. However, this technique may not be suitable for most user devices, since it requires a relatively large space to place the antenna system. Thus, several isolation techniques have been used to mitigate the mutual coupling effect of MIMO elements in a confined space. Among them are the use of parasitic structures [1], modified ground planes [2], orthogonally-oriented elements [3, 4], metamaterial structures [5, 6]. Radiation diversity has also proved to be an effective isolation technique [7-9]. As shown in [4], placing elements in orthogonal position help mitigate mutual coupling. In [10], a slotted wideband 4-element MIMO antenna is presented. The mutual coupling is only -14 dB between elements. Electromagnetic Band Gap (EBG) structure has proven to be successful in reducing the mutual coupling between MIMO elements [11, 12]. Moreover, planar and low-profile MIMO structures have proved to be successful candidates for wireless devices [13].

This letter presents a low-profile dual-band MIMO antenna for LTE1800 and LTE2600 bands for indoor applications such as LTE routers or repeaters. The design consists of four elements that are placed at the four sides of the ground plane. To enhance the isolation between these closely spaced elements, the ground plane is truncated at its lower corners. The coupling level is below −17 dB in the operating bands.

II. ANTENNA CONFIGURATION AND DESIGN

The geometry of the proposed MIMO antenna is given in Fig. 1 (a), while a photograph of the antenna prototype is shown in Fig. 1 (b). The antenna is printed on a single-sided FR4 substrate with a thickness of 0.8 mm and a dielectric constant of 4.4. The overall size of the printed MIMO antenna is 128×148 mm^2. The large size of the ground plane help improve isolation between elements and free up more space for other circuit components. Table 1 lists the dimensions of the proposed MIMO antenna. Antennas 1 and 3 are designed to operate over the LTE1800 bands, while antennas 2 and 4 operate over LTE2600 bands. The resonance of each element is

Submitted On: April 28, 2019
Accepted On: June 6, 2019

determined by its total path length. The path length of each of antennas 1 and 3 is 105 mm, while the path length of each of antennas 2 and 4 is 75 mm. The width of each trace of radiation elements is determined by rigorous parametric analysis in order to achieve good matching over the operating frequency bands. The full-wave simulation software CST Microwave Studio is used to analyze the design parameters of the proposed antenna [14].

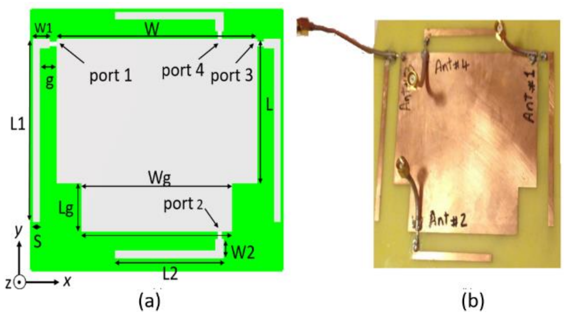

Fig. 1. (a) Geometry of the proposed MIMO antenna, and (b) photograph of the fabricated MIMO antenna.

Table 1: Dimensions of the proposed MIMO antenna

Parameter	W	L	L1	L2	W_g
Value (mm)	120	75	95	65	90
Parameter	L_g	W1	W2	g	S
Value (mm)	25	10	10	10	4

The simulated and measured reflection coefficients of antenna elements are plotted in Figs. 2 and 3. It is seen that the measured and simulated reflection coefficients (Sii, i=1,2,3,4) are in agreement with the measured data. The simulated and measured mutual couplings are shown in Fig. 4. It is seen that the measured mutual couplings (S13, S24) are all below −17 dB across LTE1800, and LTE2600 bands as shown in Figs. 4 (a) and 4 (b), respectively.

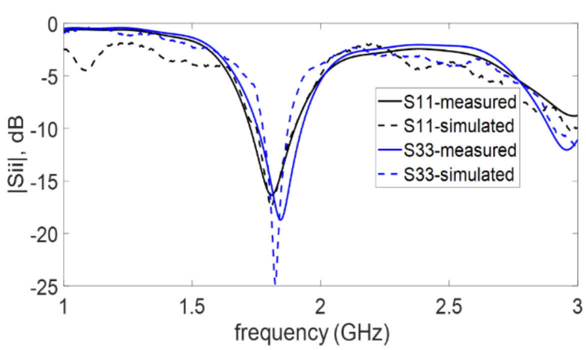

Fig. 2. Measured and simulated reflection coefficients of antennas 1 and 3.

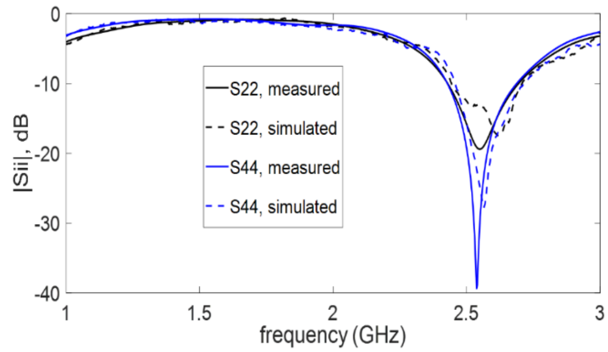

Fig. 3. Measured and simulated reflection coefficients of antennas 2 and 4.

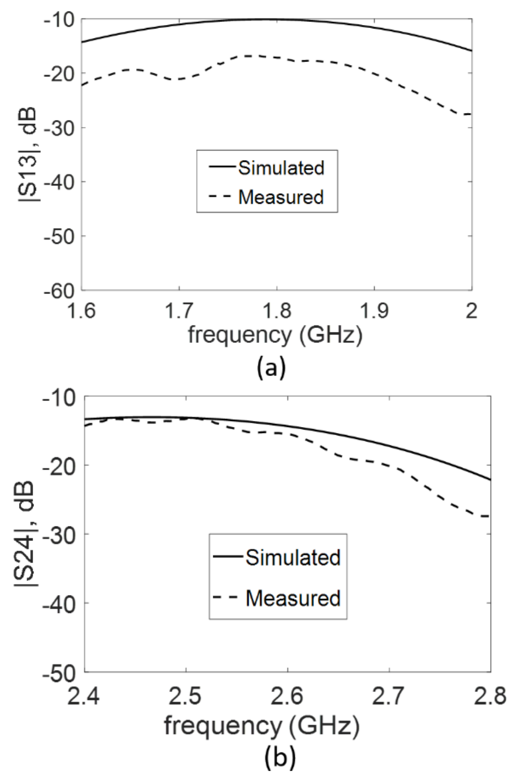

Fig. 4. Measured and simulated mutual couplings: (a) measured and simulated S13, and (b) measured and simulated S24.

The isolation behavior can be studied by comparing the current distributions of the optimized design (with trimmed lower corners of the ground plane), as shown in Figs. 5 (b) and 5 (d) with the corresponding current distributions of the proposed antenna without trimming the lower corners of the ground plane as displayed in Figs. 5 (a), and 5 (c). In Figs. 5 (a) and 5 (b), antenna 1 is excited at 1.8 GHz, while other elements are terminated by a 50-Ω port. Similarly, antenna 2 is excited at 2.6 GHz as shown in Figs. 5 (c) and 5 (d). After trimming the lower corners of the ground plane, the surface current, flowing between antennas 1 and 3, is substantially small, and hence the mutual coupling is reduced. Similarly, the trimmed lower corners have disturbed the current distribution between antennas 2 and 4, and hence an improved isolation is achieved. Although no complicated isolation structures are used, isolation is further enhanced by placing elements of same operation frequency on opposite sides of the trimmed ground plane. The separation distance between antennas 1 and 3 is 0.7λ(f=1.6 GHz), while the separation distance between antennas 2 and 4 is 0.87λ(f=2.6 GHz). That configuration has resulted in substantially reduced isolation of less than -18 dB between antennas 1 and 3 over LTE1800 bands, while the measured isolation is less than -17 dB between antennas 2 and 4 over LTE2600 bands.

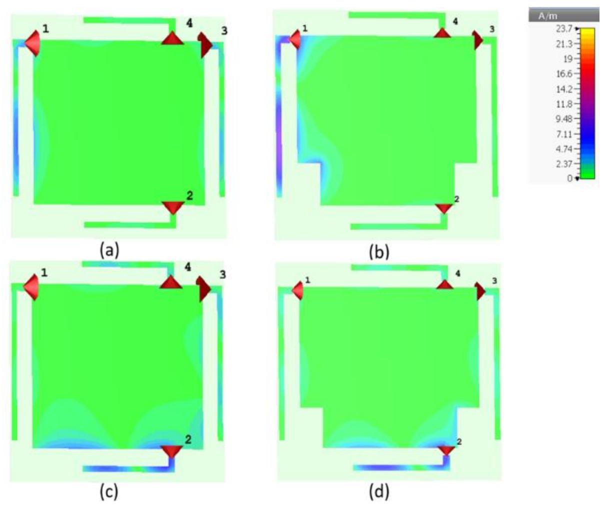

Fig. 5. Surface current distribution in A/m: (a) Antenna 1 is excited without the isolation structure, (b) Antenna 1 is excited with the isolation structure, (c) Antenna 2 is excited without the isolation structure, and (d) Antenna 2 is excited with the isolation structure.

III. RADIATION PATTERN AND DIVERSITY PERFORMANCE

The measured gain patterns of antenna elements 1 and 2 are presented in Fig. 6. The radiation patterns of antennas 3 and 4 are similar to those of antennas 1 and 2; respectively. Figures 6 (a) and 6 (b) exhibit the total gain at 1.8 GHz and 2.6 GHz in the x-z, and y-z planes; respectively. It is seen that the antenna exhibits omni-directional patterns in the x-z plane at 1.8 and 2.6 GHz, as shown in Fig. 6 (a). However, Fig. 6 (b) shows only omni-directional pattern at 2.6 GHz in the y-z plane. Figure 7 shows the total antenna efficiency and realized gain of the 4-element MIMO antenna. It is seen that efficiency of antennas 1 and 3 ranges from 69% to 85% over LTE1800 bands. And the efficiency of antennas 2 and 4 ranges from 73% to 86% over LTE2600 bands. The peak realized gain ranges from 3 to 4 dBi over LTE1800 bands, and from 2.6 to 3 dBi over LTE2600 bands. The envelope correlation coefficient (ECC) is used to evaluate the diversity performance of MIMO antenna system. In this Letter, the ECC is calculated by using measured far-field radiation patterns, as shown in Eq. (1) [15]:

$$\rho_e = \frac{\oint\{XPR.\ E_{\theta 1}(\Omega)E^{*}_{\theta 2}(\Omega)P_{\theta}(\Omega) + E_{\emptyset 1}(\Omega)E^{*}_{\emptyset 2}(\Omega)P_{\emptyset}(\Omega)\}d\Omega}{B1\,B2},$$

$$B1 = \sqrt{\oint\{XPR.\ E_{\theta 1}(\Omega)E^{*}_{\theta 1}(\Omega)P_{\theta}(\Omega) + E_{\emptyset 1}(\Omega)E^{*}_{\emptyset 1}(\Omega)P_{\emptyset}(\Omega)\}d\Omega}\,,$$

$$B2 = \sqrt{\oint\{XPR.\ E_{\theta 2}(\Omega)E^{*}_{\theta 2}(\Omega)P_{\theta}(\Omega) + E_{\emptyset 2}(\Omega)E^{*}_{\emptyset 2}(\Omega)P_{\emptyset}(\Omega)\}d\Omega}. \tag{1}$$

where XPR is the cross-polarization radiation. For an isotropic environment, XPR=1. $E_{\theta}(\Omega)$ and $E_{\emptyset}(\Omega)$ are the orthogonal θ- and ϕ-components of the antenna radiation pattern. $P_{\theta}(\Omega)$ and $P_{\emptyset}(\Omega)$ are the angular power density functions of the incident wave. As shown in Fig. 7, the computed ECC is less than 0.05 and 0.03 over LTE1800 and LTE2600 bands, respectively.

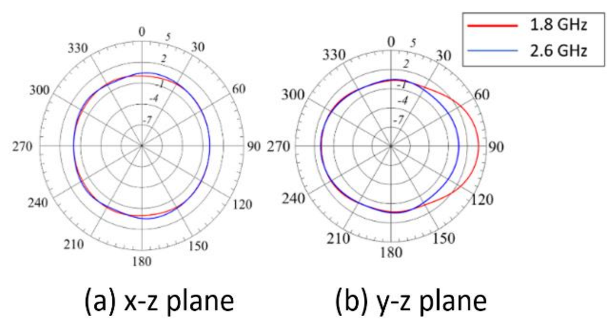

Fig. 6. Measured radiation patterns (gain in dBi) of the proposed antenna at 1.8 and 2.6 GHz: (a) x-z plane and (b) y-z plane.

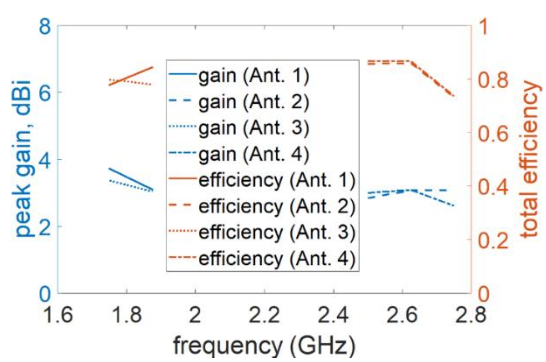

Fig. 7. Peak gain and total efficiency of MIMO antennas system over LTE1800 and LTE2600 bands.

Table 2 compares the total size (including the ground plane), covered LTE bands, efficiency, and ECC of the proposed design with some recently published results of 4-element LTE MIMO antennas. Considering the covered LTE bands, it is seen that the proposed antenna has better performance in terms of isolation and ECC compared with others listed in Table 2.

Table 2: Performance comparison between the proposed antenna and other 4-element MIMO antennas in the LTE band

Ref.	Size (mm^2)	LTE Bands (MHz)	Isolation dB	Total Efficiency %	ECC
[16]	115×83	LTE3500	< -16 dB	-	<0.03
[17]	136×68.8	LTE2300 LTE2600	<-11 dB	85-95	<0.3
[18]	108×108	LTE2100 LTE2300 LTE2600	<-12 dB	82-88	<0.2
[10]	120×140	LTE2100 LTE2300	<-14 dB	60-80	<0.25
This work	128×148	LTE1800 LTE2600	<-17 dB	69-86	<0.05

IV. CONCLUSION

A novel four-element MIMO antenna system which covers LTE1800 (1750–1880 MHz), and LTE2600 (2500–2690 MHz) as well as GSM1800 bands is proposed. The antenna elements are printed monopoles deployed on a low-profile PCB dimensions of 128×148 mm^2 and an element size of 95×5 mm^2. By utilizing spatial diversity technique and appropriately trimming the lower corners of the ground plane, the mutual couplings among the elements are all below −17 dB without using any additional decoupling structures or circuitry. The designed antennas feature very low envelope correlation coefficients, near-omnidirectional gain patterns, and reasonable total antenna efficiency values in operating bands. The measured and simulated results are in good agreement. Based on the diversity performance, radiation patterns, and s-parameters results, the antenna is a good candidate for indoor applications such as LTE routers and repeaters.

REFERENCES

[1] A. Toktas and A. Akdagli, "Wideband MIMO antenna with enhanced isolation for LTE, WiMAX and WLAN mobile handsets," *Electron. Lett*., vol. 50, no. 10, pp. 723-724, May 2014.

[2] K. Kim and K. Ahn, "The high isolation dual-band inverted F antenna diversity system with the small N- section resonators on the ground plane," *Microw. Opt. Technol. Lett.*, vol. 49, pp. 731-734, Jan. 2007.

[3] J. Malik, D. Nagpal, and M. V. Kartikeyan, "MIMO antenna with omnidirectional pattern diversity," *Electron. Lett*., vol. 52, no. 2, pp. 102-104, Jan. 2016.

[4] R. R. Ramirez and F. De Flaviis, "A mutual coupling study of linear and circular polarized microstrip antennas for diversity wireless systems," *IEEE Trans. Antennas Propag*., vol. 51, no. 2, pp. 238-248, Feb. 2003.

[5] D. A. Ketzaki and T. V. Yioultsis, "Metamaterial-based design of planar compact MIMO monopoles," *IEEE Trans. Antennas Propag*., vol. 61, no. 5, pp. 2758-2766, May 2013.

[6] K. Yu, Y. Li, and X. Liu, "Mutual coupling reduction of a MIMO antenna array using 3-D novel meta-material structures," *Applied Computational Electromagnetic Society (ACES) Journal*, vol. 33, no. 7, pp. 758-763, Mar. 2019.

[7] K. Wei, Z. Zhang, W. Chen, and Z. Feng, "A novel hybrid-fed patch antenna with pattern diversity," *IEEE Antennas Wirel. Propag. Lett*., vol. 9, pp. 562-565, May 2010.

[8] S. Karamzadeh, "A novel compact polarization diversity ultra-wideband MIMO antenna," *Applied Computational Electromagnetic Society (ACES) Journal*, vol. 32, no. 1, pp. 74-80, Jan. 2017.

[9] H. Li, L. Kang, Y. Xu, and Y.-Z. Yin, "Planar dual-band WLAN MIMO antenna with high isolation," *Applied Computational Electromagnetic Society (ACES) Journal*, vol. 31, no. 12, pp. 1410-1415, Dec. 2016.

[10] R. Anitha, P. V. Vinesh, K. C. Prakash, P. Mohanan, and K. Vasudevan, "A compact quad element slotted ground wideband antenna for MIMO applications," *IEEE Trans. Antennas Propag*., vol. 64, no. 10, pp. 4550-4553, Oct. 2016.

[11] H. Sajjad, S. Khan, and E. Arvas, "Mutual coupling reduction in array elements using EBG structures," in *Proc. International Applied Computational Electromagnetics Society Symposium*, Florence,

Italy, pp. 1-2, 2017.
[12] J. Kumar, “Compact MIMO antenna,” *Microw. Opt Technol Lett*., vol. 58, pp. 1294-1298, Mar. 2016.
[13] F. Ahmed, R. Li, and Y. Feng, “Development of a compact planar multiband MIMO antenna for 4G/LTE/WLAN mobile phone standards,” *2013 Proceedings of the International Symposium on Antennas & Propagation*, Nanjing, pp. 539-542. 2013.
[14] CST Microwave Studio, ver. 2019, Computer Simulation Technology, Framingham, MA, 2019.
[15] S. Stein, “On cross coupling in multiple-beam antennas,” *IRE Trans. on Ant. and Prop*., vol. 10, no. 5, pp. 548-557, Sep. 1962.
[16] W.-W. Lee and B. Jang, “A smart 4 by 4 MIMO antenna systems for LTE smartphones,” *Microw. Opt. Tech. Lett*., vol. 58, pp. 2668-2672, Aug. 2016.
[17] Yang and T. Li, “Box-folded four-element MIMO antenna system for LTE handsets,” *Electron. Lett*., vol. 51, no. 6, pp. 440-441, Mar. 2015.
[18] A. A. Yussuf and S. Paker, “Design of wideband MIMO antenna for wireless applications,” in *Proc. Signal Processing and Communications Applications Conference (SIU)*, Antalya, Turkey, pp. 1-14, 2017.

Mohamed Morsy received the B.S. degree in Electrical Engineering from Alexandria University, Egypt in 2004 and the M.S. and Ph.D. degrees in Electrical and Computer Engineering from Southern Illinois University, Carbondale, IL, in 2006 and 2010; respectively.

Since 2018, he has been an Associate Professor with the Electrical Engineering Department, Texas A&M University-Texarkana, Texarkana, TX. He is the author of more than 20 peer-review articles. His research interests include electromagnetic devices, antennas, RF filters, and dielectric resonators (DR). Other subjects of research are on designing antennas for the 4/5G- mobile terminals, and phased array antennas.

Morsy is an IEEE senior member and an IDEAL (Institute for the Development of Excellence in Assessment Leadership) scholar.