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Compact Triple-Band MIMO Antenna with High Isolation for Handheld Application

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Abstract

A multiband MIMO antenna design for broadband mobile's applications is proposed in this paper. Based on PIFA structure, the proposed MIMO antenna is compact in size and designed on FR4 substrate with total dimension of 37 x 43.6 x 6 mm^3. At first, a single PIFA antenna is presented using U-shaped slots in radiating patch which puts forward the antenna resonant in three frequencies: 2.4 GHz, 3.5 GHz and 6.3 GHz with bandwidth of 8.9%, 18.3% and 3% respectively for Wi-Fi, Wimax/LTE and Direct Broadcast Satellite DBS of C channel applications. Good reflection coefficient, antenna gain, and radiation pattern characteristics are obtained in the frequency band of interest. Secondly, the paper has put forward another single type of tri-band PIFA which uses double rectangular shape of Defected Ground Structure (DGS) technology. This helps increasing the antenna efficiency at all frequencies as well as enhancing antenna gain of the PIFA. Finally, a MIMO PIFA antenna is constructed by placing two single antennas side by side at close distance of 4 mm. The MIMO antenna also gets high gain and radiation efficiency at all frequencies. To reduce the mutual coupling between antenna elements, a combination of two "slot and variation" structures of DGS is proposed. Moreover, these DGS structures have enhanced MIMO antenna bandwidth at all three bands, especially at 3.5 GHz resonant frequency.

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Keywords: PIFA, Low mutual coupling, MIMO, DGS.

1. Introduction

Recently, wireless communication system has advanced incredibly, especially in mobile phone system. It is not only the dimensions of end use equipment more and more decrease but also number of internal antennas in one terminal increase rapidly [1, 2]. These demand internal antennas must be both compact to build in practical mobile handsets and have multiband for multi technologies. In last three decades, Planar Inverted F Antenna (PIFA) has emerged as one of the most promising candidate for satisfying above demands. This is due to advantages such as compact size, low profile, light weight, and high radiation efficiency [2]. However, one of the limitations of PIFA antenna is narrow bandwidth which makes this antenna type unsuitable for wide-band commercial applications.

Besides, implementing multiple Input Multiple Output (MIMO) technology is a key

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solution to increase the data rate in all future generation of wireless communication systems without needing additional frequency spectrum or transition power [3]. Therefore, all the new technologies for mobile communication require MIMO antennas such as 802.11n, 802.11ac, 802.11ad, 802.16m, LTE, LTE-Advanced, and 5G. However, MIMO antenna systems require high isolation between antenna elements, especially for application in portable devices.

There are many decoupling methods have been proposed for improving the isolation between antenna elements in the MIMO system but these solutions are not appropriate to apply for MIMO PIFA antennas. In recent years, several studies investigated for MIMO PIFA antennas using combination of decoupling solutions such as combination of slot, neutralization line, and fork-shaped line [4], using three slots of DGS (Defected Ground Structure) and spacing solution (antenna elements are place at the corners of mobile equipment so the distance of antenna elements are longer) [5], shorted strip and two slit in the ground plane [6], and combination T-shaped element and a neutral line [7]. However, most of these studies have focused on the applications for single band antenna design and several ones for dual band MIMO. Few designs of MIMO antenna with high isolation for triple band or more are proposed but all of these using spacing solution with long distance between antenna elements or combination spacing solution and other one [8-13].

In this paper, a triple band MIMO antenna with high isolation is proposed. Two U shaped slots into the main radiating patch of PIFA antenna are inserted to achieve tri-band operation at 2.4 GHz, 3.5 GHz and 6.3 GHz for Wi-Fi, Wimax/LTE-Advanced and Direct Broadcast Satellite DBS of C-band applications. To improve antenna parameters of single antenna such as radiating efficiency, gain and bandwidth, two double rectangular shapes defected ground structures (DGS) are used [14]. Moreover, other "slot and variation" shapes of DGS have proposed to reduce the mutual coupling between antenna elements (S12) below -20 dB for all three resonant frequencies. The distance of two patch antennas in the MIMO systems is 4 mm, equivalent to 0.032λ at 2.4 GHz resonant frequency. The antenna is implemented on FR4 substrate of 1.6 mm thickness with relative permittivity of 4.4 and loss tangent of 0.02. The total dimension of MIMO antenna is 37 x 43.6 x 6 mm^3 that is compact for portable devices.

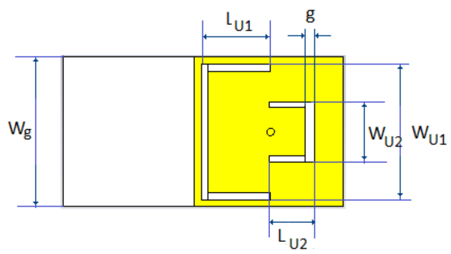
2. Antenna design

2.1. Single Antenna

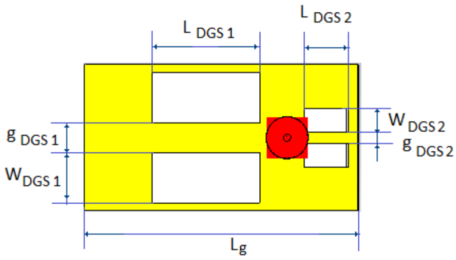
In this paper, the triple-band PIFA antenna is designed for broadband wireless access service at three different operating frequencies which are 2.4 GHz for Wi-Fi application; 3.5 GHz for LTE - tablet or Wimax application and 6.3 GHz for up-link of C band satellite one. At first, the total dimensions of the main radiating patch need to be calculated according to the desired resonant frequency. There are three different operating frequencies for the tri-band operation. Therefore, the lowest 2.4 GHz resonant frequency is chosen first to calculate approximately the total length, Lp and the width, Wp of the patch by the equation (1).

$$f_0 = \frac{c}{4(h + Lp + Wp)\sqrt{\varepsilon_r}} \tag{1}$$

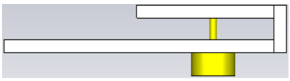
where ε_r is the relative permeability of the medium between the ground and radiating patch, h is the height of the patch in reference to the ground.



(a) Top plane



(b) Bottom plane



(c) Side plane

Figure 1. Structure of the proposed triple-band PIFA antenna.

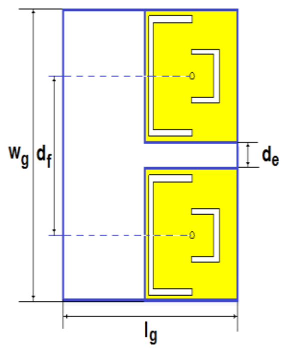
Then, two slots with U-shaped structure are added to make the second and the third resonant frequencies because this method not only achieves multiband operation but also gets enlarger bandwidth as well as minimizes guided radiation towards the user end compared to some other designs. To improve the performance of PIFA antenna, two double rectangular DGS structures are inserted in the ground plane: The large one is used to improve the antenna parameters at 2.4 GHz and 3.5 GHz resonant frequencies and the small one is used to improve the antenna parameters at 6.3 GHz. All dimensions of DGS structures are optimized by CST software. The geometric structure of the proposed tri-band PIFA antenna and the detail dimensions are shown in Figure 1 and Table 1.

Table1. Detail dimensions of the proposed antenna

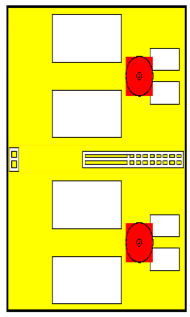
Parameter	**Value (mm)**	**Parameter**	**Value (mm)**
L_g	37	L_{DGS1}	14.5
W_g	19.8	W_{DGS1}	6.8
L_{u1}	9.2	g_{DGS1}	4
W_{u1}	18	L_{DGS2}	6
L_{u2}	6	W_{DGS2}	3.2
W_{u2}	8	g_{DGS2}	1.6
g	1	L_{DGS1}	14.5

2.2. MIMO Antenna

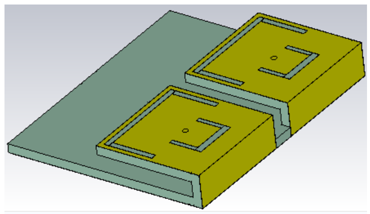
In this design, a MIMO model is constructed by placing two DGS single antenna side by side at the distance of 4 mm (0.032λ). From feeding point to feeding point, this distance equivalent to 0.5λ at 6.3 GHz resonant frequency or 0.19λ at 2.4 GHz. The layout of the MIMO antenna is shown in Figure 2 with total dimension of 37 x 43.6 x 6 mm^3.



(a) Top plane



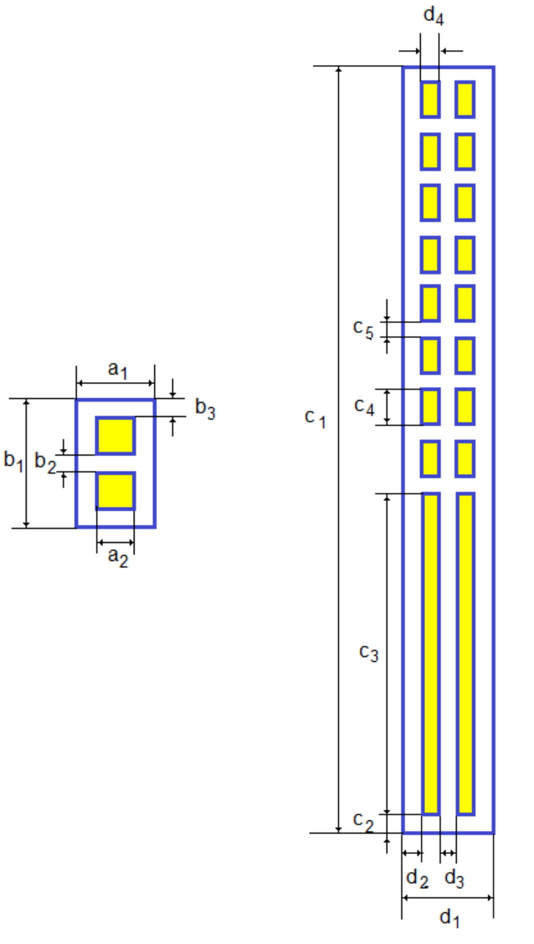
(b) Bottom plane-



(d) 3D

Figure 2. Structure of Proposed triple-band MIMO antenna.

To reduce the mutual coupling between MIMO elements for all three frequency bands, a coordinated “slot and variation” shape of DGS structure is used on ground plane. As shown in Figure 3, a small DGS structure with 8-shape is coordinated a long one with periodic loop shape to increase isolation between antenna elements at 2.4 GHz, 3.5 GHz and 6.3 GHz resonant frequencies concurrently. The dimensions of the DGS structures are optimized by CST software. Detail dimensions of the proposed MIMO antenna are shown on Table 2.



(a) (b)

Figure 3. The slot loaded structure (a) double square shape (b) periodic rectangular shape.

Table 2. Detail dimensions of MIMO antenna

Parameter	Value (mm)	Parameter	Value (mm)
d_f	23.8	c_1	21.05
d_e	4	c_2	0.5
w_1	20.1	c_3	8.85
w_2	20.6	c_4	0.9
a_1	2	c_5	0.5
a_2	1	d_1	2.4
b_1	3.4	d_2	0.5
b_2	0.5	d_3	0.5
b_3	0.5	d_4	0.45

3. Simulation results

3.1. Single Antenna

The performance of the proposed single antenna has simulated in CST software. The reflection coefficient of antenna with and without double rectangular DGS structures is shown in Figure. 4.

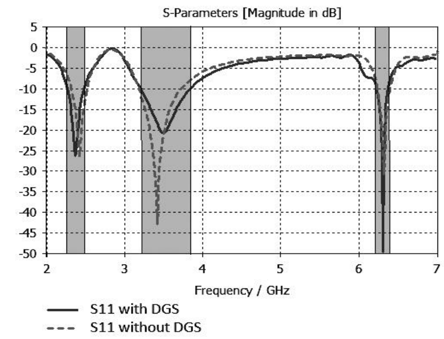
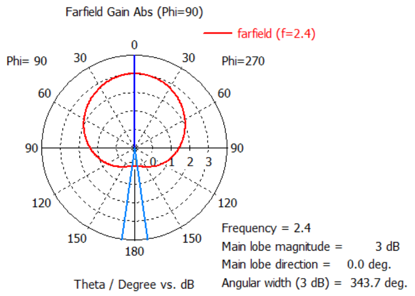


Figure 4. The reflection coefficient of antenna with and without double rectangular DGS structures.

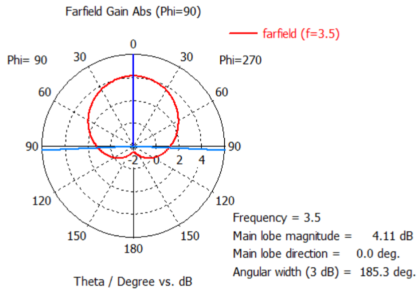
It is clearly seen that three resonant frequencies are obtained. These are 2.4 GHz, 3.5 GHz and 6.3 GHz which covers Wi-Fi, LTE/Wimax and C-band satellite band. Reflection coefficients of the proposed antenna are -26.44 dB, -42.87 dB, and -30.5 dB at resonance frequencies of 2.4 GHz, 3.5 GHz, and 6.3 GHz with the bandwidth of 201.8 MHz, 540 MHz, and 159.7 MHz respectively. By applying DGS structure to ground plane, several parameters of antenna are improved such as 100 MHz bandwidth enlarger at 3.5 GHz as shown in Figure 4, radiation efficiency and gain improvement as shown in Table 3.

Table 3. The comparison radiation efficiency and gain of single antenna with and without DGS

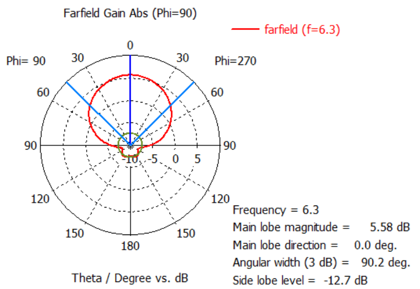
Frequency (GHz)		2.4	3.5	6.3
Radiation Efficiency (%)	With DGS	99.94	99.6	93.55
	Without DGS	98.51	98.35	81
Gain (dB)	With DGS	3.06	4.1	6.34
	Without DGS	2.95	4.1	5.45



(a) At 2.4 GHz



(b) At 3.5 GHz



(c) At 6.3 GHz

Figure 5. The 2D radiation pattern of DGS single antenna.

2D radiation patterns for the three bands of proposed antenna are illustrated in Figure 5 (a-c). It is clear that the antenna get the smooth and high directive 2D patterns. Besides, at all bands of interest, the antenna gets high radiation efficiency of over 93% as well as high gain.

3.2. MIMO Antenna

The S parameters of MIMO system are shown in Figure 6 with the distance of 4 mm. It is clearly seen that the S12 of all bands are higher -20 dB because of close distance. In addition, the bandwidths of antenna at all three bands are decreased and get 202.6 MHz, 341.7 MHz and 145.9 MHz at 2.4 GHz, 3.5 GHz and 6.3 GHz respectively due to the mutual coupling.

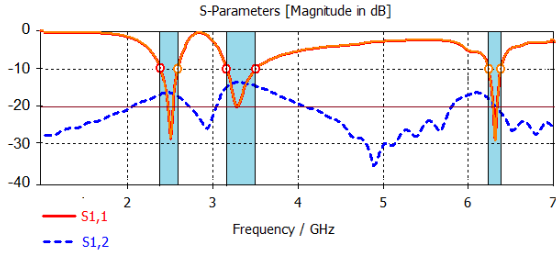
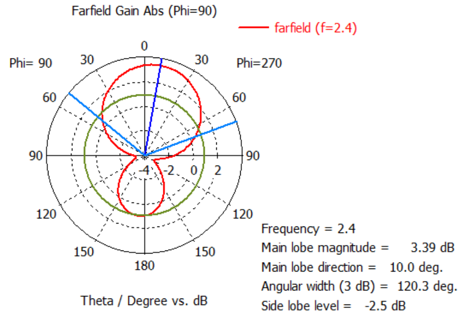
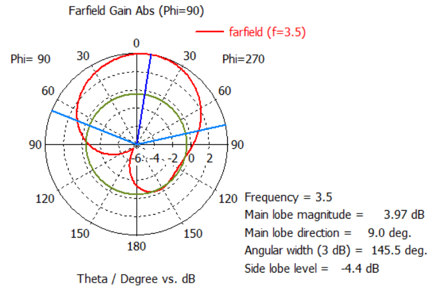


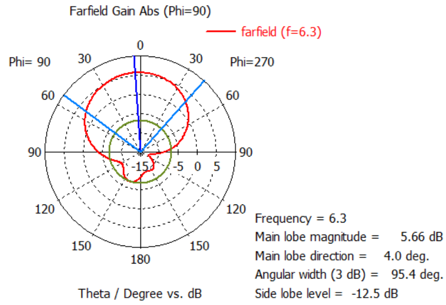
Figure 6. The S parameters of MIMO antenna with distance from feed to feed is 0.5λ at 6.3 GHz.



(a) At 2.4 GHz



(b) At 3.5 GHz



(c) At 6.3 GHz

Figure 7. The 2D radiation pattern of MIMO antenna.

The 2D radiation patterns also have distorted their shape as shown in Figure 7. However, the antenna still gets the smooth and high directive 2D patterns. In addition, the gains are better at 2.4 GHz and 3.5 GHz thanks to structure of array antenna.

To reduce the mutual coupling between two antenna element at this close distance, two “slot and variation” DGS structures with 8-shape and periodic loop shape are proposed. Recently, DGS structure is one of techniques that widely is used in MIMO antenna designs to improve isolation between antenna elements because this structure uses the dielectric as a band gap structure to suppress mutual coupling as well as to get a more compact size. However, almost previous DGS studies have achieved a low mutual coupling for flat antenna structure whose height and substrate are the same. A few researches focus on MIMO PIFA antennas but only apply to single or dual band ones. As illustrated in Figure 9, the proposed “slot and variation” DGS structure with 8-shape and periodic loop shape makes three stop-bands that is able to suppress mutual coupling for triple-band MIMO antenna. This structure is also useful for triple-band MIMO PIFA antenna. The Figure 10 shows the S parameters of the MIMO antenna using the “slot and variation” DGS structures for close distance of 4 mm (0.032λ at 2.4 GHz) from edge to edge. It is clearly seen that the mutual coupling of MIMO antenna using slot and variation DGS structures is decreased, especially at 3.5 GHz. Besides, the proposed MIMO antenna gets the high isolation between antenna elements (S12 around -20 dB) at all three bands.

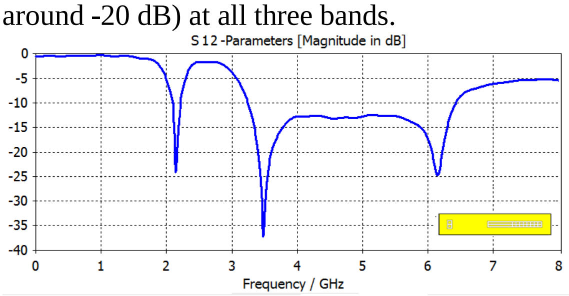


Figure 8. The S12 parameters of decoupling structure using “slot and variation” DGS.

Moreover, by applying DGS structure to the ground, the performances of several MIMO antenna parameters are improved. Firstly, the bandwidths of MIMO antenna at all three bands are increased. Especially at 3.5 GHz, the bandwidth get 573.5 MHz which is enlarged 231 MHz. Then, the total efficiency and gain of antenna are also improved lightly as shown in Table 4 while the 2D radiation patterns at interest bands are the same with smooth shape.

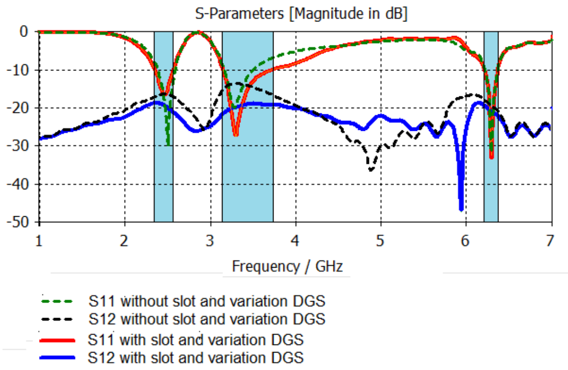


Figure 9. The S parameters of MIMO antenna with and without slot and variation DGS structures at the distance of 4 mm from edge to edge.

Table 4. The comparison radiation efficiency and gain of MIMO antenna with and without “slot and variation” DGS structure

Frequency (GHz)		2.4	3.5	6.3
Total Efficiency (%)	With DGS	92.9	93.3	90.4
	Without DGS	88.6	86.1	90.4
Gain (dB)	With DGS	3.58	4.54	6.12
	Without DGS	3.5	4.24	5.84

In MIMO antenna system, correlation factor, which is so-called enveloped correlation coefficient (ECC), will be significantly degraded with higher coupling levels. The factor can be calculated from radiation patterns or scattering parameters. For a simple two-port network, assuming uniform multipath

environment, the enveloped correlation (ρ_e), can be calculated conveniently and quickly from S-parameters as follows [17]:

$$\rho_e = \frac{|S_{11}^{*}S_{12} + S_{21}^{*}S_{22}|^2}{(1 - |S_{11}|^2 - |S_{21}|^2)(1 - |S_{22}|^2 - |S_{12}|^2)} \quad (3)$$

The correlation factor curves of the proposed MIMO antenna at three bands are shown in Figure 11. From this figure, the triple-band PIFA MIMO antenna using "slot and variation" DGS structure has the simulated ECC lower than 0.01 for three interest bands. Therefore, it is quite suitable for mobile communication with a minimum acceptable correlation coefficient of 0.5 [16] as well as for LTE equipments with value of |ρ| ≤ 0.3 for the bands of interest [17].

Table 5 shows comparison between our triple-band MIMO antenna using "slot and variation" DGS structure to get low mutual coupling and previous researches. It is obvious that the proposed antenna gets S12 parameters under -20 dB to meet the isolation demand of good MIMO antenna [18] for all three bands while distance from edge to edge is much closer than all previous studies. Besides, the other parameters such as -10 dB bandwidth and efficiency are better.

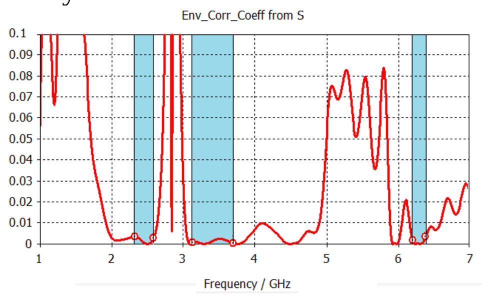


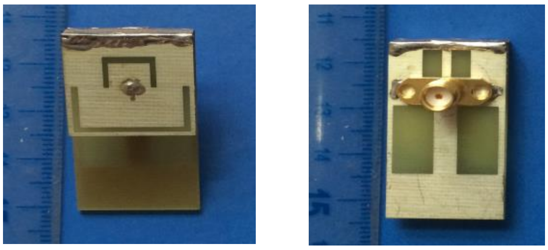
Figure 10. Correlation Factor |ρ12| curve for the proposed MIMO antenna.

Table 5. The comparison between present design and previous researches

	Resonant Frequency	Patch size at low frequency	Ground size	-10 dB Bandwidth	Mutual coupling at resonant frequency	Distance from edge to edge	Gain	Radiation efficiency
Ref [10]	2.45 GHz 5.25 GHz 5.775 GHz	15.6 x 10 x 4 mm^3	50 x 100 mm^2	4% 3.84% 2.6%	-14 dB -12 dB -13 dB	18.8 mm	3.34 dBi x x	x x x
Ref [11]	2.45 GHz 3.5 GHz 5.2 GHz 5.75 GHz	11.5 x 13.8 x 4 mm^3	50 x 100 mm^2	5.1% 2.857% 2.4% 3.65%	-15 dB -22 dB -21 dB -19.5 dB	27 mm	4.5 dBi 4.12 dBi 6.07 dBi 5.9 dBi	93% 90% 86% 87%
Ref [12]	1.77 GHz 7.86 GHz 2.02 GHz 8.89 GHz	10 x 31 x 4.5 mm^3 8 x 27 x 4.5 mm^3	40 x 100 mm^2	0% 0% 8% 0%	-7 dB -31 dB -6.8 dB -28 dB	22 mm	0.5 dBi 3 dBi 0.9 dBi 1.75 dBi	48.9% 77.2 % 45.5 % 71.39%
Ref [13]	780 MHz 1.8 GHz 3.2 GHz	9.75x17 x 6.4 mm^3	50 x 100 mm^2	0% 2.78% 9.3%	-31dB -11 dB -11 dB	16 mm	1.8 dBi	x x x
Ref [14]	900 MHz 1.8 GHz 2.6 GHz 3.5 GHz	25.7 x 17 x 0.8 mm^3	80 x 100 mm^2	6.8 % 13 % 27 % 4.2 %	-15 dB -16 dB -18 dB -40 dB	144 mm	1 dBi 3.5 dBi 3.2 dBi 1.5 dBi	x x x x
Our design	2.4 GHz 3.5 GHz 6.3 GHz	19.6 x 19.8 x 6 mm^3	37 x 43.6 mm^2	9.17 % 16.39 % 2.7 %	-20 dB -20 dB -22 dB	4 mm	3.58 dBi 4.54 dBi 6.12 dBi	92.9% 93.3% 90.4%

4. Measurement results

To verify the performance of the proposed triple-band PIFA antenna, the antennas are fabricated with single and MIMO model on FR4 substrate with the thickness of 1.6 mm.



(a) Top view (b) Bottom view

Figure 11. Fabricated single triple-band PIFA.

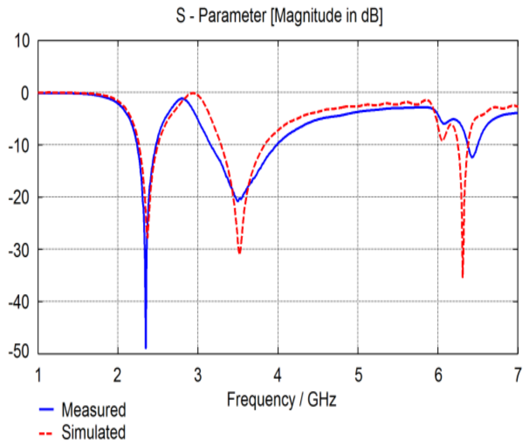
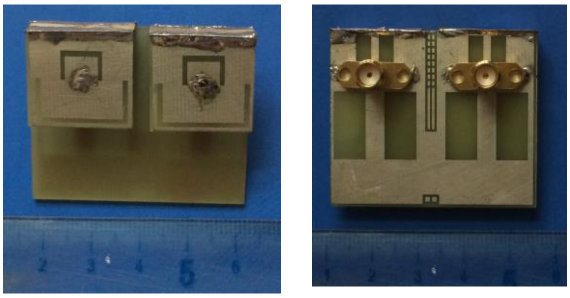


Figure 12. Measured and simulated results of S11 parameter of the proposed single PIFA antenna.

Figure 12 shows a photography of single antenna with total compact size of 37 x 19.8 x 6 mm^3. The measured result of S11 parameter is compared to simulation one in Figure 13. It is clearly seen that the single antenna operates at three bands of 2.4; 3.5 and 6.3 GHz with 10.5%, 27.5% and 4% bandwidth, respectively.

The proposed triple-band MIMO antenna using "slot and variation" DGS structure is fabricated on the FR4 substrate as shown in Figure 14. The antenna gets compact in size of 37 x 43.6 x 6 mm^3.



(a) Top view (b) Bottom view

Figure 13. Fabricated triple-band MIMO PIFA antenna.

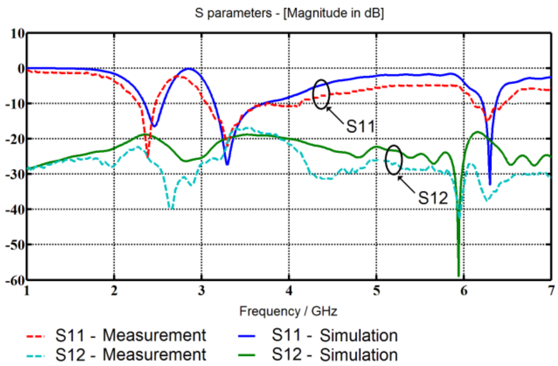


Figure 14. Measured and simulated results of S parameter of the proposed MIMO PIFA antenna.

The measured results of S parameters are compared to simulation ones in Figure 15. It is clearly seen that the MIMO antennas operate at 2.4 GHz, 3.5 GHz and 5.7 GHz with over 10%, 20% and 5% bandwidth, respectively. The mutual coupling at all interest bands are under -20 dB. It can be concluded that the measured results agree well with the simulated ones. Thus, using the proposed "slot and variation" DGS structures can reduce the mutual coupling between antenna elements in triple-band MIMO antenna to ensure the isolation demand of good MIMO antenna.

5. Conclusion

In this paper, a compact triple-band MIMO PIFA antenna using U-shape slots as well as the coordinate double rectangular with the "slot and variation" DGS structures is proposed. The total MIMO antenna occupies a small area of 37 x 43.6 mm^2 on the FR4 substrate. The MIMO antenna gets the large bandwidths which are 220 MHz, 573.5 MHz and 170 MHz at 2.4 GHz, 3.5 GHz and 6.3 GHz respectively. The proposed MIMO PIFA antenna has solved the narrow bandwidth limitation of conventional PIFA. In addition, using novel DGS structures, the antenna not only gets the extremely high radiating efficiency of more than 90% for all bands but also gets the high gain of the antenna which is respectively 3.6 dB, 4.55 dB and 5.86 dB at 2.4 GHz, 3.5 GHz and 6.3 GHz operating frequency, respectively. Besides, the MIMO antenna has ensured the mutual coupling between antenna elements under -20 dB for all three bands with the narrow distance of 4 mm. This proposed antenna is suitable for handheld terminals of Wi-Fi, Wimax/LTE and C-band satellite applications.

Acknowledgments

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References

[1] Hang Wong, Kwai-Man Luk, Chi Hou Chan, Quan Xue, Kwok Kan So, Hau Wah Lai, "Small antennas in Wireless Communications," Proceedings of the IEEE Journal, vol. 100, no 7, pp. 2109-2121, 2012.

[2] Rowell, C., Lam, E.Y., "Mobile phone antenna design," IEEE Antennas and Propagation Magazine, vol. 54, no. 4, pp. 14-34, 2012.

[3] Murch, R.D., and Letaief, K.B., "Antenna systems for broadband wireless access," IEEE Communication Magazine, vol. 40, pp. 76-83, 2002.

[4] Ahmed A. Naser, Khalil H. Sayidmarie, and Jabir S. Aziz, "Compact High Isolation Meandered-Line PIFA Antenna for LTE (Band-Class-13) Handset Applications," Progress In Electromagnetics Research C, vol. 67, pp. 153–164, 2016.

[5] Mustapha El Halaoui et al., "Dual Band PIFA for WLAN and WiMAX MIMO Systems for Mobile Handsets," 9th International Conference Interdisciplinarity, Tirgu-Mures, Romania, pp. 878-883, October 2015.

[6] Do-Gu Kang, Jinpil Tak, and Jaehoon Choi, "MIMO Antenna with High Isolation for WBAN Applications," International Journal of Antennas and Propagation, Volume 2015, Article ID 370763, 7 pages, 2015.

[7] Ajinkya Vekhande, Ajinkya Joshi, Madhur Kapse, Sagar Lohit, Yashashree Bhange, "Dual Band Print Antenna for Wireless Applications with Enhanced Isolation," Int. Journal of Engineering Research and Applications, vol. 5, no. 4, pp. 82-84, 2015.

[8] Majid Manteghi and Yahya Rahmat-Samii, "A Novel Miniaturized Triband PIFA for MIMO Applications," Micowave and Optical Technology Letters, vol. 49, no. 3, pp. 724-731, 2007.

[9] Rashid Ahmad Bhatti, Jung-Hwan Choi, and Seong-Ook Park, "Quad-Band MIMO Antenna Array for Portable Wireless Communications Terminals," IEEE Antenna and Wireless propagation Letters, vol. 8, pp. 129-132, 2009.

[10] K. Zhao , S. Zhang, and & S. L. He, "Closely-Located MIMO Antennas of Tri-Band for WLAN Mobile Terminal Applications," Journal of Electromagnetic Waves and Applications, vol. 24, pp. 363–371, 2010.

[11] J. Jasper Sweetlin, T. Anita Jones Mary, "Mutual Decoupling in Quad Band MIMO Slotted PIFA for Wireless Applications," The International Journal of Engineering and Science (IJES), vol. 1, no. 2, pp. 303-307, 2012.

[12] Jianfeng Zhu, Botao Feng, Li Deng, Biao Peng, and Shufang Li, "Coupled-Fed Tri-Band MIMO Antenna for WWAN and LTE Application," Microwave and Optical Technology Letters, vol. 59, no. 2, pp. 463-468, February 2017.

[13] Duong Thi Thanh Tu, Nguyen Gia Thang, Vu Van Yem, "A Triple-band PIFA Antenna Design Using Defected Ground Structure for Handheld Applications". International Conference on Science and Technology, pp.745-750, Nov 2016.

[14] J. Thaysen and K. B. Jakobsen, "Envelope correlation in (N, N) MIMO antenna array from

scattering parameters," Microwave and Optical Technology Letter, vol. 48, pp. 832-834, 2006.

[15] M. P. Karaboikis, V. C. Papamichael, G. F. Tsachtsiris, and V. T. Makios, "Integrating compact printed antennas onto small diversity/MIMO terminals," IEEE Transactions on Antennas and Propagation, vol. 56, pp. 2067-2078, 2008.

[16] 3GPP TS 36.101, V8.3.0. "EUTRA User Equipment Radio Transmission and Reception," September 2008.

[17] Istvan Szini, Alexandru Tatomirescu, and Gert Frølund Pedersen, "On Small Terminal MIMO Antennas, Harmonizing Characteristic Modes with Ground Plane Geometry", IEEE Antenna Propag. Trans. On, vol. 63, no. 4, pp. 1487 - 1497, 2015.