TRIPLE-BAND MIMO ANTENNA DESIGN WITH LOW MUTUAL COUPLING USING DEFECTED GROUND STRUCTURE

THIẾT KẾ ANTEN MIMO BA BĂNG VỚI ĐỘ TƯƠNG HỖ THẤP SỬ DỤNG CẤU TRÚC MẶT ĐẤT KHUYẾT DGS

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Abstract:

The multiband MIMO antenna design for broadband mobile's applications is proposed in this paper. The proposed MIMO antenna that is based on the PIFA structure and designed on FR4, gets compact in size with total dimension of 37x43.6x6 mm^3. At first, a MIMO PIFA antenna is presented using U-shaped Slots on radiating patch and two rectangular DGSs on the ground plane which puts forward the antenna resonant in three frequencies: 2.46 GHz, 3.3 GHz, and 6.3 GHz with bandwidths of 8.44%, 9.76% and 2.3% respectively for Wi-Fi, Wimax/LTE and Direct Broadcast Satellite DBS of C channel applications. Good return loss, antenna gain, and radiation pattern characteristics are obtained in the frequency band of interest. Then, to reduce the mutual coupling between antenna elements at close distance of 4 mm, equivalent to 0.032λ at 2.4 GHz resonant frequency, a novel "slot and variation structure" of DGS is proposed. Moreover, this DGS has enhanced MIMO antenna bandwidth at all three bands, especially at 3.5GHz resonant frequency.

Key words:

PIFA, MIMO, DGS, low mutual coupling MIMO antenna.

Tóm tắt:

Nội dung bài báo đề xuất một kiến trúc anten MIMO đa băng cho các ứng dụng băng rộng trong các thiết bị cầm tay di động. Với cấu trúc PIFA, anten MIMO đề xuất sử dụng vật liệu FR4 đạt được kích thước khá nhỏ 37x43.6x6 mm^3. Cộng hưởng tại 3 tần sô 2.46 GHz, 3.3Ghz và 6.3 GHz nhờ khe chẻ hình chữ U trên mặt bức xạ với độ rộng băng thông tương ứng 8.44%, 9.76% và 2.3%, anten có thể đáp ứng được đồng thời cho các ứng dụng WiFi, Wimax/LTE và vệ tinh băng C. Các tham số anten khác như độ lợi, suy hao phản xạ, hiệu suất bức xạ,… đều đạt chuẩn công nghệ. Không những thế, nhờ sử dụng cấu trúc mặt phẳng đất khuyết (DGS), anten MIMO đề xuất đạt độ cách ly cao (S12<-20 dB) với khoảng cách giữa hai phần tử bức xạ khá nhỏ, 4mm, tương đương với 0.032λ tại tần số cộng hưởng 2.4GHz. Bên cạnh đó, nhờ cấu trúc DGS này, băng thông của anten MIMO cũng được mở rộng thêm, đặc biệt tại tần số cộng hưởng 3.5G Hz.

Từ khóa:

PIFA, MIMO, DGS, anten MIMO có độ tương hỗ thấp.

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1. INTRODUCTION

Recently, the 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 the number of internal antennas in one terminal increase rapidly [1-2]. These demand the internal antennas must 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 [2-3]. However, one of the limitations of PIFA antenna is narrow bandwidth which makes this antenna type unsuitable for wide-band commercial applications.

To make multiband PIFA antenna, there are several methods that have been proposed such as meandering the main radiating element [4], using fractal method [5] or introducing slot on the ground plane [6]. These techniques achieve multiband operation but get the performance degradation. Another technique is using multi-stacing or multi-shorting pins [7]. However, this method is not only complex to fabricate but also needs much effort in assembling the PIFA antenna to get multiband operation.

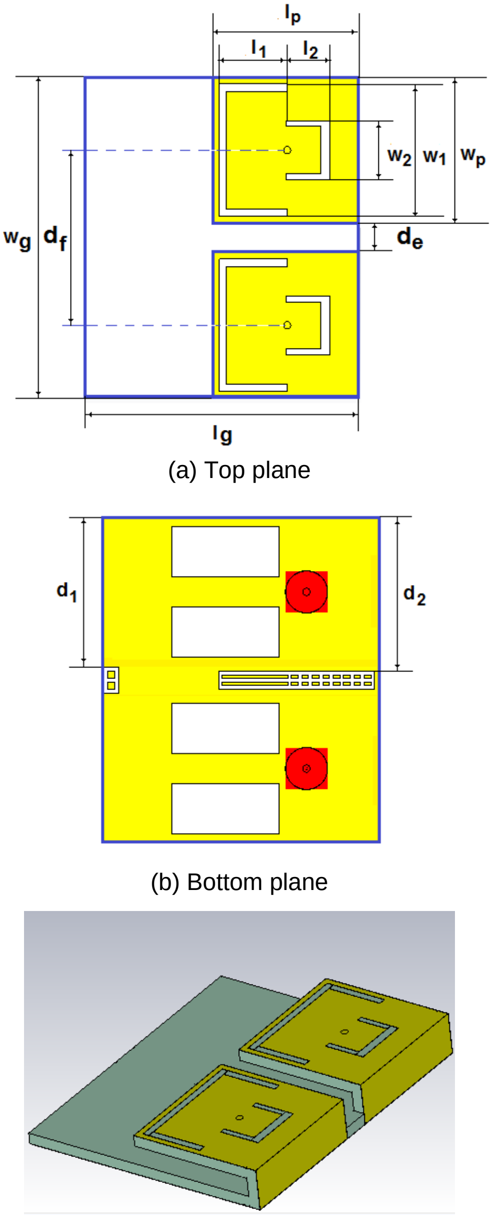
Besides, Multiple Input Multiple Output (MIMO) technology has attracted much attention presently in the terminal of modern wireless communication systems such as: 802.11n, 802.11ac, 802.16m, LTE-advanced, 5G. The most significant feature of MIMO is the high channel capacity increasing without bandwidth addition or transmission power increasing. However, MIMO antenna systems require high isolation between antenna elements and a compact size for application in portable devices. There are many methods have been proposed for improving the isolation between antenna elements in the MIMO system such as using transmission line decoupling technique [8], neutralization line technique [9], covering the patch by additional dielectric layers [10], using shorting pins for cancellation of capacitive polarization currents of the substrate [11] or using photonic band gap structures such as defected ground structure (DGS) and EBG [12-14]. However, most of these studies have focused on the applications for single band antenna design and a few for dual band MIMO antenna system. The design of MIMO antenna with high isolation for triple band or more with narrow distance is still a huge challenge in MIMO system for handheld applications.

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 is inserted to achieved tri-band operation at 2.46 GHz, 3.3 GHz and 6.3 GHz for Wi-Fi, Wimax/ LTE-advanced and Direct Broadcast Satellite DBS of C channel applications. The total dimension of MIMO antenna is 37 × 43.6 × 6 mm^3 that is compact for handheld portable devices.

2. PROPOSED ANTENNA STRUCTURE

The geometric structure of the proposed

tri-band PIFA MIMO antenna is shown in figure 1. The antenna consists of three main elements which are finite ground plane, top radiating patch and shorting pin that connects between the top radiating patch and ground plane.



(a) Top plane

(b) Bottom plane

(c) 3D

Figure 1. Proposed triple-band MIMO antenna

At first, the total dimension of 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 to calculate the total length (l_p) and width (w_p) of the patch by equation (1).

$$f_0 \approx \frac{c}{4(l_p + w_p)} \tag{1}$$

where c is the speed of light, l_p and w_p are the length and the width of top radiating plate and f_0 is resonant frequency.

Then, two slots with U-Shaped structure have been chosen to make the second and the third resonant frequencies. The resonant frequencies are approximated by formula (2):

$$f_{r1} = \frac{c}{4(h + l_1 + w_1)\sqrt{\varepsilon_r}}$$
$$f_{r2} = \frac{c}{4(h + l_2 + w_2)\sqrt{\varepsilon_r}} \tag{2}$$

where ε_r is the relative permittivity of the medium between the ground and radiating patch, h is the height of the patch in reference to the ground. To improve the performance of PIFA antenna, the double rectangular DGS structures are inserted in the ground of each antenna elements [15].

After that, a MIMO model is constructed by placing two antenna elements side by side at the distance of 23.8 mm from feeding point to feeding point, equals to 0.5λ at 6.3 GHz resonant frequency or 0.19λ at 2.4 GHz. From edge to edge, the distance between two patches of MIMO antenna is 4 mm, equivalent to 0.032λ at 2.4 GHz resonant frequency. The total dimension of MIMO antenna is 37 × 43.6 × 6mm^3 that is compact for handheld applications.

(a) (b)

Figure 2. The slot load DGS structures (a)Double square shape, (b)Periodic rectangular shape

Table 1. Detail dimension of proposed MIMO antenna

Parameter	*Value (mm)*	*Parameter*	*Value (mm)*
l_g	37	w_2	8
w_g	43.6	l_p	19.6
l_1	9.2	w_p	19.8
w_1	18	d_e	4
l_2	6	d_f	23.8

Finally, to reduce the mutual coupling MIMO elements for all three bands of antenna, two coordinated "slot and variation" shape of DGS structures are used on the ground plane. As shown in Figure 2, the small DGS structure with 8-shape is coordinated the long one with periodic loop shape to increase the isolation at 2.44 GHz, 3.3 GHz and 6.3 GHz resonant frequencies concurrently. The dimensions of these DGS structures are optimized by CST software. The detail dimension of the proposed MIMO antenna is shown on table 1.

3. SIMULATION RESULTS

The performance of proposed MIMO antenna has simulated in CST software. The S parameters of MIMO system is shown in figure 3 with the distance of two antenna elements from feed to feed is changed from 62.5 mm (0.5λ at 2.4 GHz resonant frequency) down to 23.8 mm (0.5λ at 6.3 GHz resonant frequency).

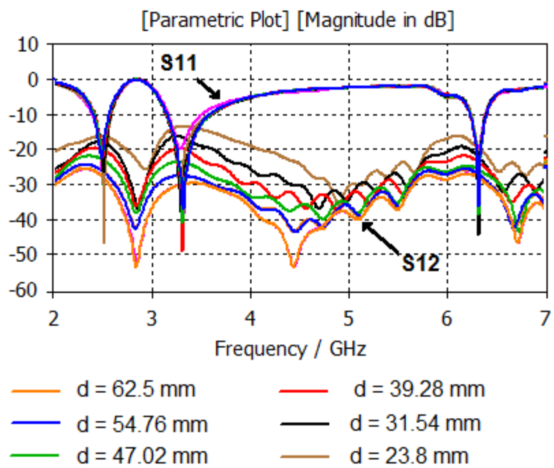


Figure 3. The S parameters of MIMO system with distance is changed from 62.5 mm down to 23.8 mm

It is clearly seen that there are three frequencies at which resonance occurs. They are 2.46 GHz, 3.3 GHz and 6.32 GHz. Thanks to double rectangular DGS structures, the mutual coupling between antenna elements is quite low with the distance of 0.5λ at 2.4 GHz resonant frequency. At this distance, the S12 gets -28 dB at 2.4 GHz as well as 6.3GHz and -30 dB at 3.5 GHz. These values of S12 increase gradually and reach -20 dB at distance of 39.28 mm which equal in 0.31λ at 2.4 GHz or 0.46λ at 3.5 GHz. At distance of 23.8 mm (0.5λ at 6.3 GHz), the bandwidths of MIMO antenna get 202.6 MHz, 341.7 MHz and 145.9 MHz and the S12 values reach -16 dB, -13 dB and -19 dB at 2.4 GHz, 3.5 GHz and 6.3 GHz respectively.

To reduce the mutual coupling between two antenna elements at this close distance, two "slot and variation" DGS structures with 8-shape and periodic loop shape are proposed.

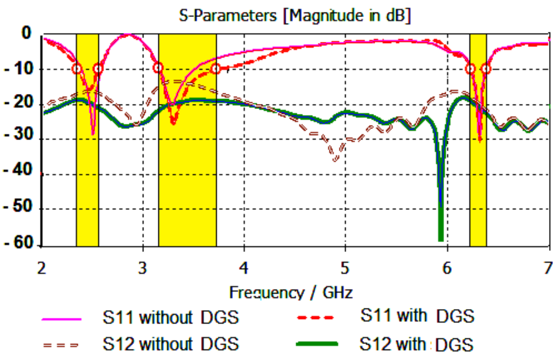


Figure 4. The S parameters of MIMO system using DGS with the distance of 4mm from edge to edge

The figure 4 shows the S parameters of the MIMO antenna using the "slot and variation" DGS structures for the distance of 23.8 mm (0.5λ at 6.3 GHz) from feed to feed. This distance equals the distance of 4 mm from edge to edge. It is a so narrow distance between two antenna elements in a MIMO system. It is clearly seen that the MIMO antenna using the DGS gets the high isolation between antenna elements (S12 <-20 dB) at all three bands. Moreover, by applying DGS structure on the ground, several performance parameters of MIMO antenna are improved. First of all is the bandwidth. The bandwidth of MIMO antenna at all three bands are increased and get 209.5 MHz, 573.5 MHz and 150.7 MHz at 2.44 GHz, 3.33 GHz and 6.32 GHz respectively. There is a significant increase of 231.85 MHz at 3.5 GHz resonant frequency.

Table 2. The radiation efficiency and gain

Frequency (GHz)	*Radiation Efficiency (%)*		*Gain(dB)*	
	With DGS	*Without DGS*	*With DGS*	*Without DGS*
2.4	99.94	98.51	3.6	3.56
3.5	99.6	98.35	4.55	4.24
6.3	93.55	81	5.86	5.85

Then, the radiation efficiency and gain of MIMO antenna are also improved lightly as shown in table 2. In addition, from figure 5, it is clearly seen that, the 2D radiation pattern of MIMO antenna is smooth for all of three bands and angular width (3 dB) is 117; 127 and 96 degree at 2.4 GHz, 3.5 GHz and 6.3 GHz respectively.

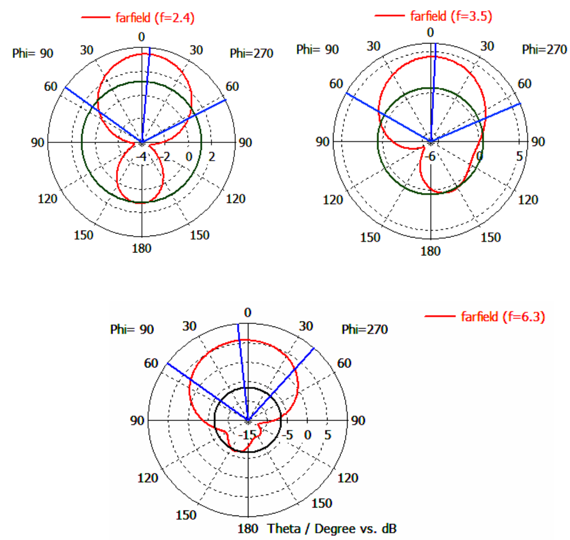


Figure 5. The 2D radiation pattern of MIMO antenna using "slot and variation" DGS

Moreover, the proposed MIMO antenna is compared to another MIMO design without connecting ground between antenna elements as shown in figure 6.

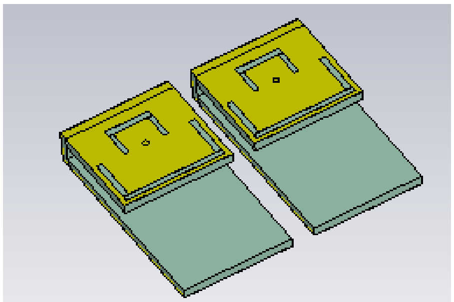


Figure 6. MIMO antenna without connecting ground

The comparison of S parameters between the proposed MIMO antenna and the MIMO antenna without connecting ground is illustrated in figure 7.

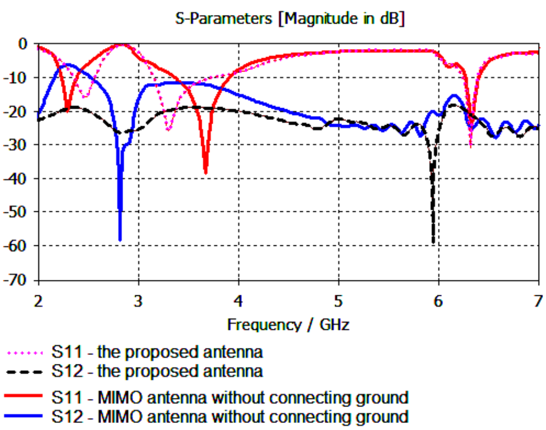
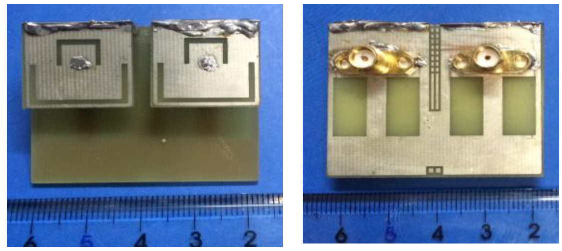


Figure 7. Comparison of S parameters between the proposed MIMO antenna and the MIMO antenna without connecting ground

It is clearly seen that the MIMO antenna without connecting ground gets high mutual coupling between antenna elements. At 2.28 GHz resonant frequency, antenna mutual coupling gets -7 dB and at 3.7 GHz resonant frequency, it is -10 dB. Thus, several antenna parameters tend to drop such as bandwidth, desired resonant frequency.

4. MEASUREMENT RESULTS

The proposed triple-band MIMO antenna is fabricated on the FR4 substrate as shown in figure 8.



(a) Top view (b) Bottom view

Figure 8. Fabricated triple-band MIMO antenna

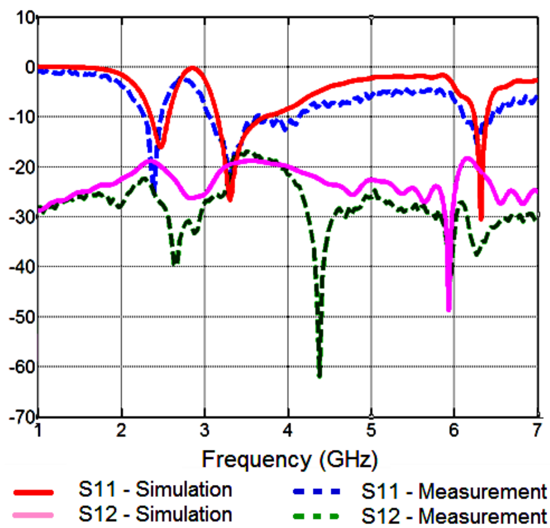


Figure 9. Comparison of S parameters between measurement results and simulation results

The antenna gets compact in size of 37×43.6×6 mm^3. The measured results of S parameters are compared to simulation ones in figure 9. It is clearly seen that the MIMO antennas operate at about 2.4 GHz, 3.5 GHz and 5.7 GHz with over 10%, 20% and 4% bandwidth, respectively. The mutual coupling at all interest bands are under-20dB. 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.

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 37×43.6 mm^2 on the FR4 substrate and can operate at 2.4 GHz, 3.5 GHz and 6.3 GHz. The MIMO antenna gets the large bandwidths which are 209.5 MHz, 573.5 MHz and 150.7 MHz at 2.4 GHz, 3.5 GHz and 6.3 GHz respectively. These results have 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 99.94%; 99.6% and 93.55% 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. Besides, the MIMO antenna has ensured the mutual coupling between antenna elements under -20 dB for all three bands with the narrow distance of 4mm from edge to edge of two antenna elements. This proposed antenna is suitable for handheld terminals of Wi-Fi, Wimax/LTE and C-band satellite applications.

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Biography:

Duong Thi Thanh Tu, received B.E, M.E degrees in Electronics and Telecommunications from Hanoi University of Science and Technology and National University in 1999 and 2005, respectively. She now is a lecturer at Faculty of Telecommunications 1, Posts and Telecommunications Institute of Technology. She, presently is doing PhD at School of Electronics and Telecommunications, Hanoi University of Science and Technology. Her current research centers on antenna design for next generation wireless networks as well as the special structure of material such as metamaterial, electromagnetic band gap structure.