4x4 MULTIBAND MIMO ANTENNA USING DOUBLE SEMI-CIRCLE STRUCTURE FOR 5G MILIMETER WAVE APPLICATIONS

ANTEN MIMO ĐA BĂNG SỬ DỤNG CẤU TRÚC HÌNH BÁN NGUYỆT KÉP CHO ỨNG DỤNG 5G BĂNG TẦN MILIMET

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Ngày nhận bài: 29/03/2019, Ngày chấp nhận đăng: 30/07/2019, Phản biện: TS. Hoàng Thị Phương Thảo

Abstract:

5G antenna is so compact size but has to get large bandwidth, high gain and good radiation efficiency to be able to support huge data rate for 4.0 revolution industry. In this paper, a novel 4x4 multiband Multiple Input Multiple Output (MIMO) antenna is designed. Using the semi-circle structure, the proposed antenna not only achieves wide band but also is easy to optimize operate frequencies at millimeter wave band. Besides, the 4x4 MIMO antenna gets high isolation without distance from edge to edge of single antennas thanks to using round Electromagnetic Band Gap (EBG) structure. Based on Roger RT5880, the antenna patch gets a compact size of nearly 15 mm^2, operates at three band of 28 GHz, 38 GHz and 43 GHz of 5G mobile bands with the bandwidth of 7.14%, 9.74% and 24.84%, respectively. All simulation results are based on CST software.

Keywords:

5G, MIMO, Multiband, Antenna, EBG.

Tóm tắt:

Anten 5G băng tần milimet tuy kích thước nhỏ nhưng lại yêu cầu băng thông rộng, hệ số khuếch đại cao, hiệu suất bức xạ tốt để có thể cung cấp tốc độ truyền tải dữ liệu lớn, đáp ứng được yêu cầu truyền thông 4.0. Nội dung bài báo đề xuất cấu trúc anten MIMO 4x4 đa băng hình bán nguyệt kép, đạt băng rộng, dễ dàng tối ưu tần số cộng hưởng, ứng dụng cho truyền thông băng tần milimet. Bên cạnh đó, anten còn sử dụng thêm cấu trúc dải chắn băng tần EBG hình tròn nhằm nâng cao độ cách ly khi các anten đơn đặt sát cạnh nhau không có khoảng cách. Sử dụng vật liệu Roger RT5880, anten đạt kích thước bức xạ nhỏ gần 15 mm^2, hoạt động tại ba băng 28 GHz, 38 GHz và 43 GHz của truyền thông di động 5G băng tần milimet với độ rộng băng thông tương ứng 7.14%, 9.74% và 24.84%. Các kết quả đề xuất đều được thực hiện trên phần mềm mô phỏng đã được thương mại hóa CST.

Từ khóa:

5G, MIMO, đa băng, anten, EBG.

1. INTRODUCTION

The wireless communication system has advanced incredibly from the first to the fourth generation and is going to be in the fifth one (5G) [1]. 5G technology is estimated to work at millimeter wave whose frequency spectrums are 24.25-27.5 GHz; 27.5-29.5 GHz; 37-40.5 GHz; 42.5-43.5 GHz; 45.5-50.2 GHz; 50.4-52.6 GHz; 6-76 GHz and 81-86GHz [2] in which the bands of 28GHz and 38 GHz are under consideration the most. These millimeter wave bands would bring new challenges in implementation of antennas [3] such as multiband, wide band and MIMO one.

To make multiband 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 antenna to get multiband operation.

Besides, 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; neutralization line technique covering the patch by additional dielectric layers; using shorting pins for cancellation of capacitive polarization currents of the substrate but most of them apply for the bands which are less than 10 GHz. There are a few researches to improve isolation for MIMO antenna designs which operate at millimeter wave bands [8]-[12]. However, almost 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 is still a huge challenge in MIMO system for handheld applications.

In this paper, a triple band MIMO antenna using round EBG structure with high isolation is proposed. The patch of double semi-circle structure has achieved tri-band operation at 28 GHz, 38 GHz and 43 GHz for 5G millimeter wave applications. The total dimension of 4×4 MIMO antenna is $16.36 \times 18.26 \times 0.79$ mm^3 that is compact for handheld portable devices.

2. ANTENNA STRUCTURE

Figure 1 shows a recursive procedure of forming double semi-circle for making multiband antenna.

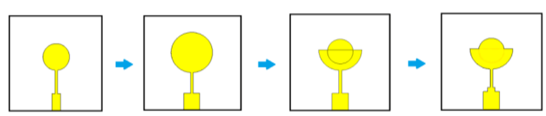


Figure 1. Recursive procedure of forming double semi-circle antenna

Firstly, dimension of radiating patch need to be calculated according to the desired resonant frequency. There are three different operating frequencies for the tri-band operation. The lowest 28 GHz resonant frequency is calculated by the lager circle while the 38 GHz resonant frequency is determined by the smaller circle. The circumscribed radius of each circle, a, is calculated approximately by the following equations [13]:

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi \varepsilon_r F}\left[ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{1/2}} \quad (1)$$

$$F = \frac{8.791x10^9}{f_r\sqrt{\varepsilon_r}} \quad (2)$$

where ε_r is the dielectric constant, f_r is the resonant frequency and h is the height of the substrate.

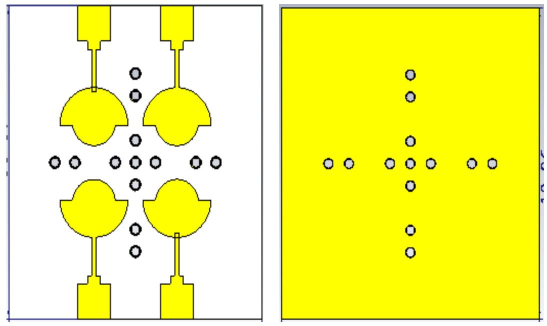
After that, the combination of two above single antennas is formed and it makes the third band by the difference between two semi-circles. Finally, the feed line is optimize to match with the antenna through a quarter wave transformer and a characteristic impedance of 50 Ω is obtained approximately by the following equations [13]:

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{eff}}x\left[\frac{W}{h} + 1.393 + \frac{2}{3}ln\left(\frac{W}{h} + 1.444\right)\right]} \quad (4)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{\frac{1}{2}} \quad (5)$$

where ε_{eff} is the effective dielectric constant and W is the width of the feeding line. The single antenna gets a total size of 11×11×0.79 mm^3.

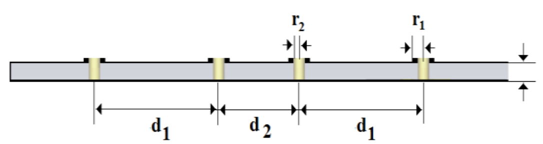
The geometric structure of the proposed tri-band MIMO antenna is shown in Figure 2. The MIMO model is constructed by placing two antenna elements side by side in horizontal as well as vertical at the distance of about 0.5λ at 28 GHz resonant frequency from circle center to circle center. From edge to edge, the distances between patches are so tiny. The smallest distance is about 0.96 mm which is equal 0.0896λ at 28GHz.



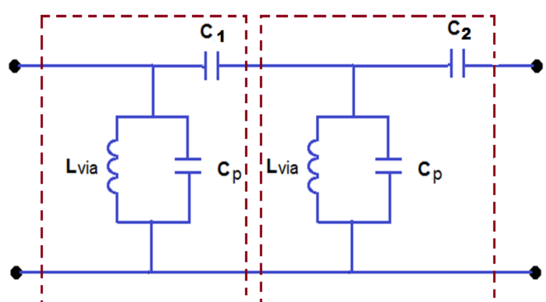
(a) Top plane (b) Bottom plane

Figure 2. The proposed multiband MIMO antenna

To reduce the mutual coupling between MIMO elements for all three bands of antenna, a novel EBG structure which is developed from non-periodic and round EBG structure [14] is proposed and placed among patches. This structure has a cross shape which is made of four parts. Each part is a non-periodic and round EBG and makes a multi-band decoupling structure as shown in Figure 3.



(a) A structure of non-periodic and round EBG



(b) Equivalent circuit

Figure 3. The proposed EBG structure

Table 1. Dimension of the EBG structure

Parameter	*Value (mm)*	*Parameter*	*Value (mm)*
r_1	0.3	d_1	6.5
r_2	0.265	d_2	4.25
h	0.79		

3. SIMULATION RESULTS

The performance of the proposed MIMO antenna as well as EBG structure have simulated in CST software.

3.1. Band-gap characteristic of EBG structure

The S12 parameter of EBG structure is shown in Figure 4. It is obvious that there are two an average of 20dB reduction in the transmission coefficient. Optimizing by CST simulation, we get two stop bands of 17GHz-29.5 GHz and over 33 GHz frequency band. Thus, it is suitable for decreasing mutual coupling for multiband MIMO antenna which operates at 28 GHz, 38 and 43GHz bands of 5G application.

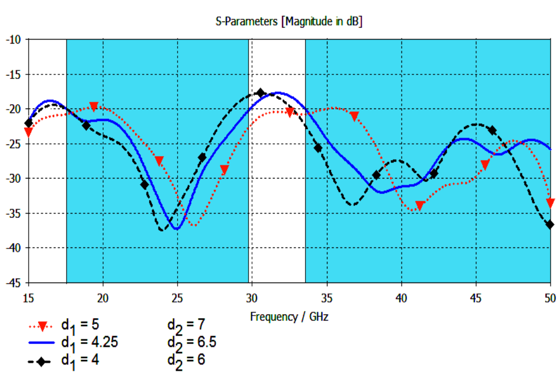


Figure 4. Simulated transmission coefficient of the proposed round patch EBG structure with different d_1 and d_2

3.2. 4x4 multiband MIMO antenna with EBG

The simulation results of the reflection coefficients of 4×4 double semi-circle MIMO antennas using round patch EBG structure are shown in Figure 5. It is clearly seen that here are three frequencies at which resonance occurs. They are 28 GHz, 38 GHz and 43 GHz with large bandwidth of 2 GHz, 3.7 GHz and 10.68 GHz, respectively. These bandwidths cover four bands of 5G which are 27.5-29.5 GHz; 37-40.5 GHz; 42.5-43.5 GHz; 45.5-50.2 GHz.

Thanks to cross EBG structures, the mutual coupling between antenna elements is quite low with the S12 get under -15 dB at nearly all over operating bands. It is the same for Enveloped Correlation Coefficient (ECC) which is one of important factors in MIMO antenna. ECC of the proposed 4×4 MIMO antenna can be obtained using formula show in Equation (6) where i=1 to 4, j=1 to 4, and N=4 [15].

$$|\rho_e(i,j,N)| = \frac{\left|\sum_{n=1}^{N} S_{i,N}^{*} S_{N,j}\right|}{\sqrt{\left|\prod_{k(=i,j)}\left[1-\sum_{n=1}^{N} S_{i,N}^{*} S_{N,k}\right]\right|}} \quad (6)$$

Using CST software, the correlation factor curve of the proposed MIMO antenna at three bands is shown in Figure 6. From this figure, the tri-band MIMO antenna using round EBG structure has the simulated ECC lower than 0.02 for all interest bands. Therefore, it is quite suitable for mobile communication with a minimum acceptable correlation coefficient of 0.5 [16].

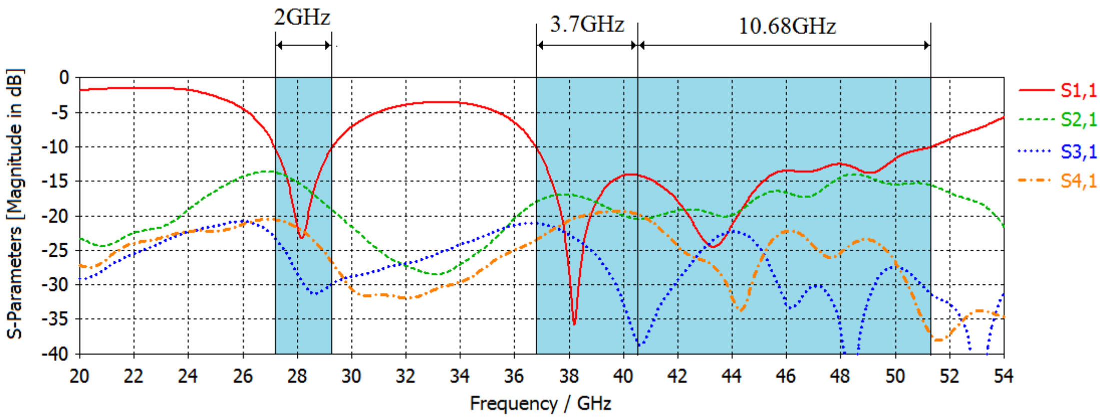


Figure 5. The S parameters of MIMO antenna

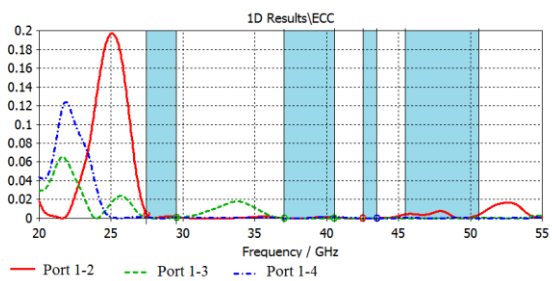


Figure 6. ECC curve for MIMO antenna

The 2D radiation patterns of the proposed MIMO antenna are shown in Figure 7 with high directivity. The antenna gain gets 6.05 dB, 7.49 dB and 7.43 dB at 28 GHz, 38GGHz and 43 GHz respectively.

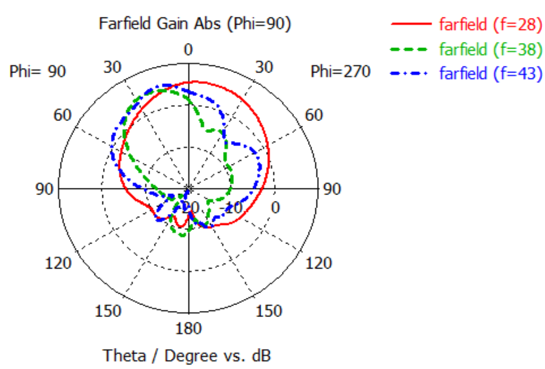


Figure 7. The 2D radiation pattern of the proposed antenna

The radiation efficiencies are rather good. The antenna radiation gets 78%, 88% and 86% at 28 GHz, 38 GGHz and 43 GHz respectively as shown in Figure 8.

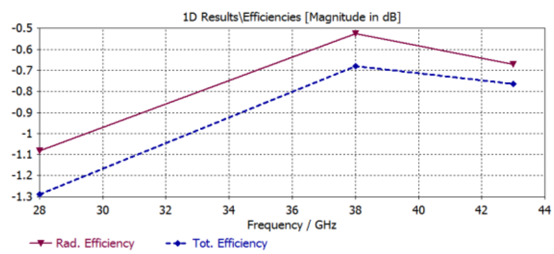


Figure 8. The efficiency of the proposed antenna

4. CONCLUSION

In this paper, a compact multiband MIMO antenna using double semi-circle structure as well as the cross structure of round patch EBG is proposed. The total MIMO antenna occupies a small area of 16.36 × 18.26 × 0.79 mm^3 on the RT5880 substrate and can operate at 28 GHz, 38 GHz and 43 GHz. The MIMO antenna gets the large bandwidths which are 2 GHz, 3.7 GHz and 10.68 GHz, respectively. These results are able to apply for the wide bandwidth of four bands of 5G application which are 27.5-29.5 GHz; 37-40.5 GHz; 42.5-43.5 GHz; 45.5-50.2 GHz.

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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 received PhD degree from the School of Electronics and Telecommunications, Hanoi University of Science and Technology in April 2019. She now is a senior lecturer at Faculty of Telecommunications 1, Posts and Telecommunications Institute of Technology. Her research interests include antenna design for next generation wireless networks as well as the special structure of material such as metamaterial, electromagnetic band gap structure.

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