DUAL ANTENNA FOR IoV APPLICATIONS BASED ON 802.11bd

ANTEN KÉP CHO CÁC ỨNG DỤNG IoV DỰA TRÊN CHUẨN 802.11bd

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Abstract:

The Internet of Vehicles (IoV) is a development in the transportation industry that makes the ITS (Intelligence Transportation System). This system is based on two standards: Dedicated Short Range Communication (DSRC) and Vehicle to Everything (V2X) in which IEEE 802.11bd 2022 is the latest evolution of radio access technologies for V2X communications. Operating in two bands of 5.9 GHz and 60 GHz, the advanced IoV antennae face the challenge of the large gap between two resonant frequencies. In this study, a dual antenna is proposed with one being a circular patch to achieve a resonance of 5.9 GHz and the other being a 1x2 array structure to make a 60 GHz band. Using a composed structure of a shorting pin and DGS (Defected Ground Structure), the proposed antenna gets not only a compact size but also wide bandwidths, good gains, and high radiation efficiencies for both bands of IoV communication. All results are validated using CST simulation software.

Keywords:

IoV, shorting pin, array antenna, DGS, milimeter wave.

Tóm tắt:

Các phương tiện giao thông kết nối internet là một bước phát triển tiên tiến trong nền công nghiệp giao thông, hình thành nên hệ thống giao thông thông minh ITS (Intelligence Transportation System). Hệ thống này dựa trên hai tiêu chuẩn chính: Truyền thông tầm ngắn chuyên dụng DSRC (Dedicated Short Range Communication) và Phương tiện giao thông kết nối với mọi thứ V2X (Vehicle to Everything) trong đó khuyến nghị IEEE 802.11bd 2022 là chuẩn mới nhất cho công nghệ truy nhập vô tuyến cho truyền thông V2X. Hoạt động tại hai băng tần 5,9 GHz và 60 GHz, anten IoV tiên tiến phải đối mặt với một thách thức về khoảng cách vô cùng lớn giữa hai băng tần thiết kế. Trong nghiên cứu này, chúng tôi đề xuất một cấu trúc anten kép trên cùng một đế điện môi với phần tử bức xạ hình tròn tạo ra tần số cộng hưởng 5,9 GHz và cấu trúc mảng 1x2 hình thành nên băng 60 GHz. Bên cạnh đó, chúng tôi cũng kết hợp cấu trúc đường ngắn mạch và mặt phẳng đất không hoàn hảo DGS (Defected Ground Structure) để đạt được kích thước nhỏ, băng thông rộng, hệ số khuếch đại tốt và hiệu suất bức xạ cao, đáp ứng được yêu cầu cho cả hai băng tần của truyền thông IoV. Tất các kết quả được phân tích và đánh giá trên phần mềm mô phỏng đã được thương mại hóa CST.

Từ khóa:

IoV, đường ngắn mạch, anten mảng, DGS, sóng milimet.

1. INTRODUCTION

In recent years, the Internet of Vehicles (IoV) is not only a tendency but also a motivation in the development of the transportation industry. IoV is regarded as an advanced version of the VANET network, primarily designed to provide safe driving capabilities [1]. With the number of vehicles constantly increasing, this tendency presents both opportunities and challenges for the development of IoV systems, which operate based on DSRC and C-V2X standards. V2X operates on the IEEE 802.11p and 802.11bd standards while Dedicated Short Range Communication (DSRC), and Cellular-V2X (C-V2X) based on mobile systems such as LTE, 5G, and IEEE 802.11 one [2].

As technology progresses, the V2X standard is currently being developed based on the 802.11bd standard which is called as the next-generation V2X communication which uses two bands of 5.9 GHz and 60 GHz [3]. However, with a huge gap between these two frequency bands, it is a significant challenge to designing antennas to ensure stable operation. There are several studies solving this problem but their radiation efficiency is not quite good, ranging from 62-80% [4], 85% [8], [9]. The narrow bandwidth is only 1.27% [5], and the low gain reaches -3.13dB [6].

In this paper, we proposed a dual antenna operating at two frequencies of 5.9GHz and 60 GHz which is designed in the same substrate. Based on a complex structure of the shorting pin, DGS, and circle patch, the antenna not only gets a compact size but also achieves high performance in both frequency bands, making it suitable for most modern IoV systems.

2. ANTENNA DESIGN

The antenna consists of two parts: a microstrip antenna operating at a frequency of 5.9 GHz and an array antenna operating at a frequency of 60 GHz. The two antennas are placed together on RT5880 substrate with dielectric constant εr = 2.2, loss tangent δ = 0.0009, height h = 0.252 mm. The antenna uses the microstrip transmission line feeding method with dimensions calculated in case the transmission line impedance is chosen to be 50 Ω:

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{eff}}\left[\frac{W}{h} + 1.393 + \frac{2}{3}\ln\left(\frac{W}{h} + 1.444\right)\right]} \qquad (1)$$

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

where ε_{eff} is the effective dielectric constant, W is the width of the microstrip feeding.

The radiating element of the antenna consists of 2 parts: a rectangular array and a circular patch antenna that uses a shorting pin to reduce the size of the antenna.

2.1. 5.9 GHz antenna

In TM_{nm} mode, the antenna's resonant frequency is determined by the formula:

$$f_{nm} = \frac{X_{nm}c}{2\pi a_e\sqrt{\varepsilon_r}} \quad (3)$$

To achieve the smallest size, the mode n = 1, m = 1 is selected with X_{11} = 1.84118, c is the speed of light in free space, ϵ_r is the dielectric constant of the substrate, a_e is the effective radius of the circular patch is determined according to:

$$a_e = a\left\{1 + \frac{2h}{\pi a \varepsilon_r}\left(ln\frac{\pi a}{2h} + 1.7726\right)\right\}^{\frac{1}{2}} \quad (4)$$

where a is the circular patch radius. This formula gives relatively accurate results with an error probability of less than 2.5% when $\frac{a}{h} \gg 1$. The middle part of the patch uses a copper shorting pin with outer radius a_1 = 0.5 mm and inner radius a_2 = 0.47 mm to reduce the size of the patch.

2.2. 60 GHz antenna

In TM_{nm} mode, the resonant frequency of the antenna is determined by the formula:

$$f_{nm} = \frac{c}{2\pi\sqrt{\varepsilon_r}}\sqrt{\left(\frac{m\pi}{L_1}\right)^2 + \left(\frac{n\pi}{W_1}\right)^2} \quad (5)$$

where W_1 is the width and L_1 is the length of each patch.

$$W_1 = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad (6)$$

Extended length of patch:

$$\Delta L = 0{,}412h\frac{(\varepsilon_{eff} + 0.3)(\frac{W_1}{h} + 0.264)}{(\varepsilon_{eff} - 0.258)(\frac{W_1}{h} + 0.8)} \quad (7)$$

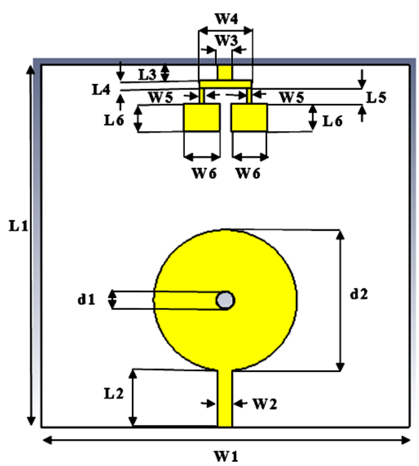
Actual length of each patch:

$$L_1 = \frac{c}{2f\sqrt{\varepsilon_{eff}}} - 2\Delta L \quad (8)$$

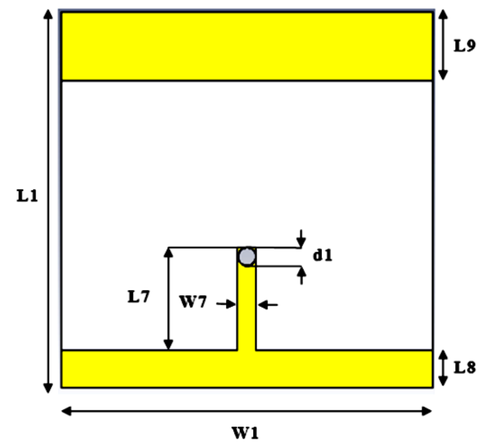
The antenna structure and all its dimensions are shown in Figure 1 and Table 1.

Table 1. Dimensions of the antenna

Parameters	Value (mm)	Parameters	Value (mm)
W1	20	L1	20
W2	0.78	L2	3.1
W3	0.78	L3	0.84
W4	2.82	L4	0.45
W5	0.23	L5	0.84
W6	1.98	L6	1.52
W7	1	L7	5.5
d1	1	L8	2
d2	3.9	L9	3..63



(a) Top view



(b) Bottom view

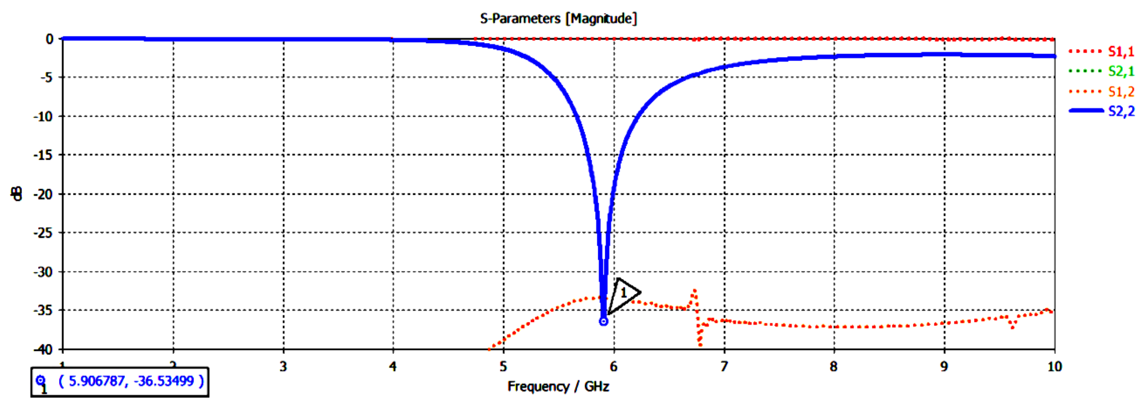
Figure 1. Structure of the proposed antenna

3. SIMULATION RESULTS

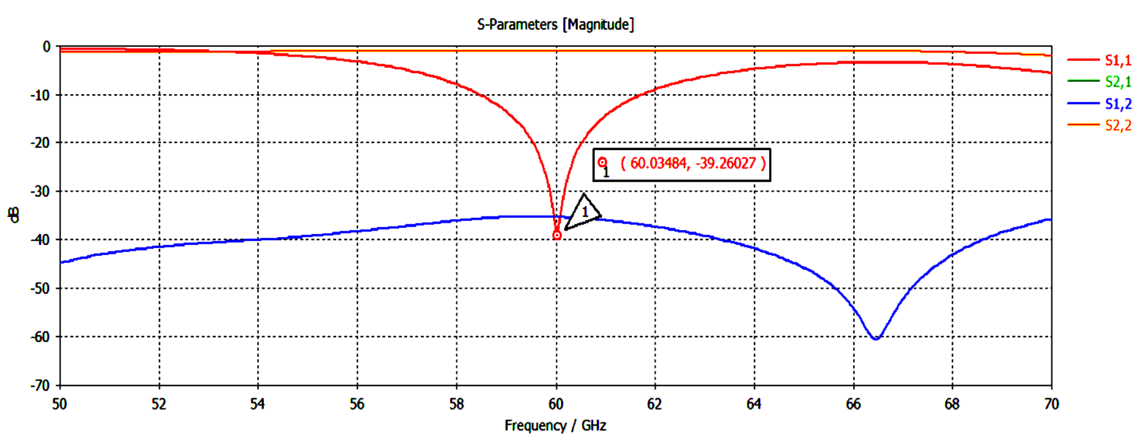
In this section, simulation results of the antenna are analyzed on CST MICROWAVE STUDIO software that including scattering parameters, radiation efficiency, and gain in both frequency ranges which are from 1 to 10 GHz and from 50 to 70 GHz.

- 1 to 10 GHz:

From Figure 2(a), it can be seen that the antenna operates at 5.9 GHz with a wide bandwidth of 590 MHz (from 5.64 to 6.23 GHz). The mutual coupling from the 60 GHz array antenna is so low that is under -30 dB.



(a) From 1 to 10 GHz



(b) From 50 to 70 GHz

Figure 2. S parameters of the dual antenna

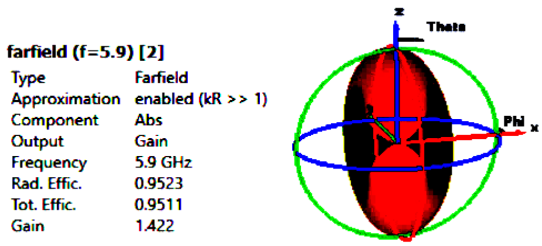


Figure 3. 3D radiation pattern

The 3D and 2D radiation patterns of the 5.9 GHz antenna are shown in Figures 3 and 4. It is obvious that the antenna gets a good gain with an omi-directional radiation pattern.

Based on the RT5880 substrate, the proposed antenna achieves a high efficiency whose total efficiency is 95.11%, and radiation efficiency is 95.23%.

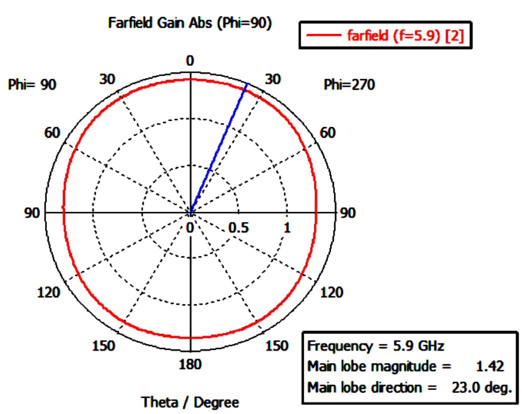


Figure 4. 2D radiation pattern

- 50 to 70 GHz:

From Figure 2(b), it can be seen that the antenna operates at 60 GHz with a wide bandwidth of 3.32 GHz (from 58.41 to 61.73 GHz). The mutual coupling from the 5.9 GHz antenna is also so low that is under -30 dB.

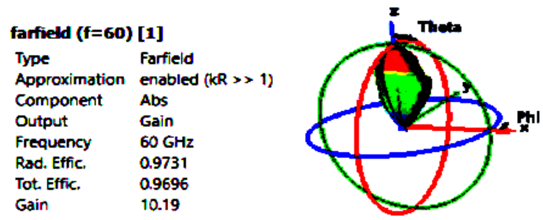


Figure 5. 3D radiation pattern of 60 GHz antenna

The 3D and 2D radiation patterns of the 60 GHz array are shown in Figures 5 and 6. It is obvious that the array achieves a good gain of over 10 dB with a directional radiation pattern. Based on the RT5880 substrate, the proposed array also achieves a high efficiency whose total efficiency is 96.96%, and radiation efficiency is 97.31%.

The comparison of our study with other 5.9/60 GHz antennae is presented in Table 2. It can be seen that the proposed dual antenna can operate at two well-known bands of 5.9 GHz and 60 GHz for 802.11bd with a wideband, good gain, and high radiation efficiency. It is able to provide flexibility for IoV applications.

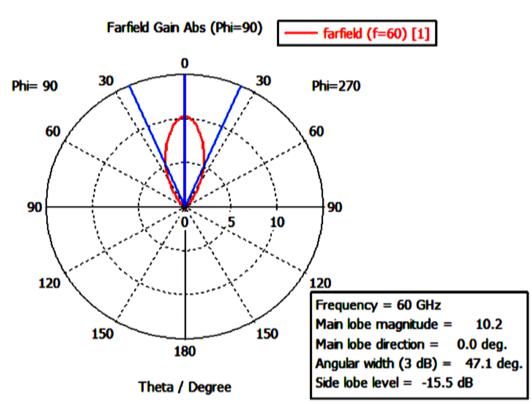


Figure 6. 2D radiation pattern of 60 GHz antenna

Table 2. Comparison of the proposed antenna and recent publish works

Ref	Sub	f GHz	B (%)	Gain (dBi)	η (%)
[4]	FR4	5.9	13.56	5.5	62-80
[5]	AD270	5.9	1.27	5.2	-
[6]	Arlon/ Diclad 880	5.9	10.67	–3.13	-
[7]	Isola tachyon	60	7.02	10.47	90
[8]	Rogers	60	6	18.5	85
[9]	LTCC	60	15	6.3	85
This work	RT5880	5.9 60	10 5.53	1.42 10.19	95.23 97.31

4. CONCLUSION

In this paper, we proposed a dual antenna that can operate at both bands of 5.9 GHz and 60 GHz of 802.11bd standard. Using a short pin and asymmetrical DGS, the proposed antenna gets a compact size of 20×20×0.252 mm^3 which makes it suitable for IoV applications with limited space. With a good gain and high radiation efficiency, the antenna is expected to provide reliable and high-performance connectivity in modern diverse traffic environments.

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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 is Senior lecturer at Faculty of Telecommunications 1, Posts and Telecommunications Institute of Technology.

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