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A Pencil-Beam Planar Dipole Array Antenna for IEEE 802.11ac Outdoor Access Point Routers

Tang The Toan[1], Nguyen Manh Hung[1]
Nguyen Minh Tran[1], Truong Vu Bang Giang[2,*]

[1] *University of Hai Duong*
[2] *VNU University of Engineering and Technology, 144 Xuan Thuy, Cau Giay, Hanoi, Vietnam*

Abstract

In this paper, a new design of pencil-beam planar dipole array antenna (PDAA) with reflector back has been designed and fabricated for IEEE 802.11ac outdoor applications. The proposed antenna is a planar array combined with a reflector. The planar array is comprised of $4 \times 4 \times 3$ single elements which are placed on an FR4-epoxy substrate with the size of 241 mm × 194 mm × 1.6 mm. This design has very good simulation results in terms of the radiation pattern, gain and input impedance bandwidth. A very high gain of 18.2 dBi has been achieved at 5.5 GHz, and the bandwidth is relatively wide with about 23% of the center frequency, which covers the whole bandwidth allocated for the application. A prototype has been fabricated and measured. The measurement results have very good agreements with the simulated data.

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1. Introduction

Nowadays, Internet users are demanding for more streaming videos, database searches, file transfers, and cloud-based storage applications on a daily basis. This places increasing requirements on a future network ability to provide consistent bandwidth, data rate [1, 2]. The IEEE 802.11ac, the fifth generation in Wi-Fi networking standards, promises to bring extraordinary improvements in data rate, wireless reliability, coverage and quality, which can meet human demands. This new standard operates only at 5 GHz band compared with the existing 802.11 standards working at both 2.4 GHz band and 5 GHz band, and allows to support very wide bandwidth up to 160 MHz. However, the propagation loss in this band is about 8 dB higher than that at 2.4 GHz. Therefore, for outdoor applications especially, antennas required to gain more than 10 dBi [3].

In the literature, several high gain antennas have been proposed [4-7]. Reference [4] presented a new design of PDAA including of 4×8 elements for WLAN application. The antenna can operate at 5.2/5.8 GHz with really wide bandwidth of 1.97 GHz and high gain of 17.53 dBi at 5.8 GHz. M. Song and J. Li

* Corresponding author. Email.: giangtvb@vnu.edu.vn

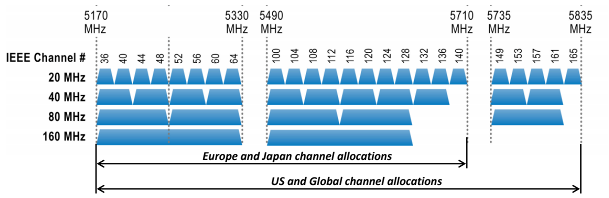


Fig. 1. Bandwidth channel allocations for IEEE 802.11ac.

[5] proposed a high gain array antenna with 8×4 elements applied for WLAN/WiMAX applications. The antenna can cover the frequency band of 5.07 - 5.94 GHz at -15 dB return loss (or $VSWR < 1.43$). The highest gain of the proposed antenna is about 22.78dBi at 5.5GHz and the HBPW is 12.04^0 at E-plane. In addition, the antenna array with six antenna elements for the application of IEEE 802.11a has been developed in [6]. The operation frequency range is 5 - 6 GHz, and the simulated gain is about 11dBi. In [7], a high gain antenna array for 60 GHz millimeter wave identification (MMID) has been studied. The antenna was placed on Taclamplus substrate with thickness of 0.1 mm and relative permittivity $\epsilon = 2.1$ at 60 GHz. This proposal can achieve the gain of 23 dBi, but the operational bandwidth is only 3% of the center frequency.

In this paper, a high gain planar array antenna with 8×6 elements has been proposed for IEEE 802.11ac outdoor applications. The antenna has been designed on a FR4-epoxy substrate, which has the permittivity of $\epsilon = 4.2$ and the 3D size of 241 mm×194 mm×1.6 mm. The constructed array can provide a wide impedance bandwidth (about 23%) with the return loss less than -10dB which can well meet the bandwidth allocated worldwide. The maximum gain of the proposal is about 18.2 dBi at 5.5 GHz and the HBPW is 12.1^o at E-plane. A prototype has been fabricated and measured. The comparison between simulation results and measured data has also been presented, and good agreements have been obtained.

2. Design and simulation of the array

2.1. Antenna design

In order to build an array, a single element has been designed to operate at the 5.37 GHz. The design of the patch follows the equations of designing the rectangular shape patch in [8]. As the structure of double-sided printed dipole, the antenna consists of two patches arranged symmetrically on two side of the FR4-epoxy substrate. The width of the patch is approximately $\lambda_{eff}/4$ (6 mm), and the input impedance of this patch has been calculated by the equation (1) [9]. This single element is fed at the center by the 50 Ohm transmission line, and the width of this line can be deduced from the equation (2). In order to improve the impedance bandwidth, the rectangular patch has been truncated at the top corner. The final shape of the element is shown in Fig. 2.

$$Z_{in} \approx 90\frac{\epsilon_r^2}{\epsilon_r - 1}\left(\frac{L}{W}\right)^2 \quad (1)$$

$$Z_c = \frac{\eta}{\pi\sqrt{\epsilon_{re}}}\left\{\frac{W}{h} + 1.393 + 0.677ln\left(\frac{W}{h} + 1.44\right)\right\}^{-1} \quad (2)$$

where W is the width of the line, ϵ_{re} is the effective permittivity of the substrate, and h is the substrate thickness.

After designing the single patch, the corporate feeding network has been introduced to construct the array. In

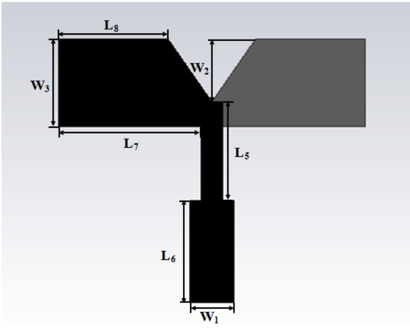


Fig. 2. The configuration of single element.

Table 1. The parameters of the single element (unit: mm)

Parameters	Value	Parameters	Value
w_1	3	L_5	6.7
w_2	4.3	L_6	7
w_3	6	L_7	9.75
L_8	7.5		

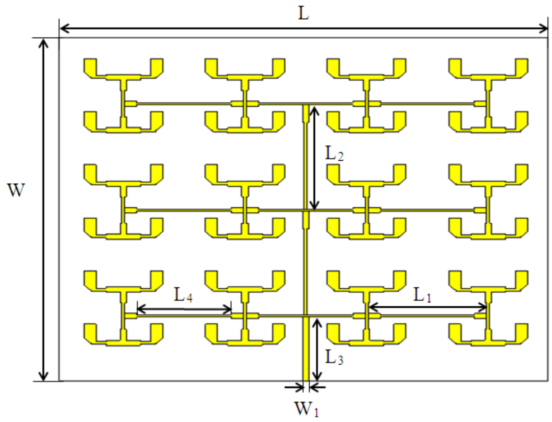


Fig. 3. The proposed array antenna.

Table 2. The parameters of the planar array (unit: mm)

Parameters	Value	Parameters	Value
L	241	L_2	59
W	194	L_3	36
L_1	59	L_4	46.5

particular, the T-junction dividers are utilized to guarantee the equivalent power at each element of the array. The proposed array consists of 12 sub-arrays, with 2 × 2 elements in each one. In addition, the sub-arrays have been spaced at regular distances of approximately λ (L_1, L_2) to ensure that all sub-arrays will be in phase. The final geometrical arrangement of 4 × 4 × 3 elements with dimensions of 241 mm × 194 mm has been constructed and presented in Fig. 3. The reflector, which is an FR4 board with the same size of the radiating array, is placed 6 mm away from the main planar array.

2.2. *Simulation Results*

The simulated return loss of the array has been indicated in Fig. 4. The simulated result shows that the operating range of the antenna covers from 4.5 to 5.9 GHz when the return loss is less than -10 dB. Therefore, it is proved that the antenna can work well at the channel bandwidth allocated for IEEE 802.11ac.

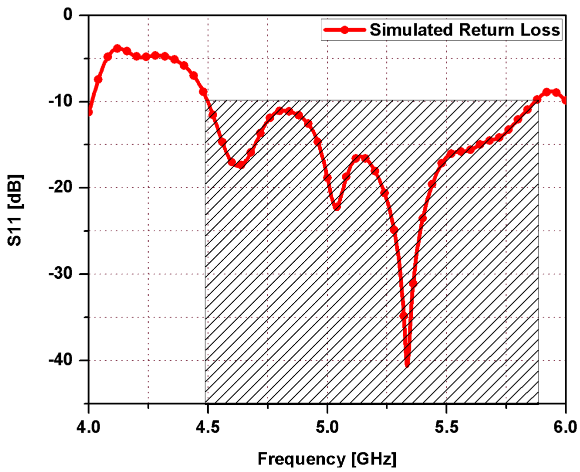


Fig. 4. The simulated return loss of the array.

The gain of the antenna model is also presented in Fig. 5 and Fig. 6. It is easily seen that the max gain is 18.2 dBi (at 5.5 GHz) and the average gain of the array at the whole 5 GHz band is really stable at about 17.5 dBi, which meets the gain requirement for outdoor applications.

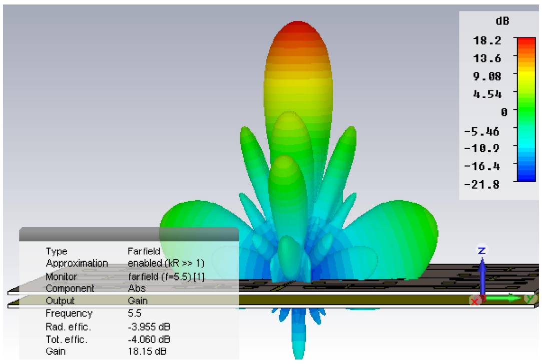


Fig. 5. The 3D gain total at 5.5 GHz.

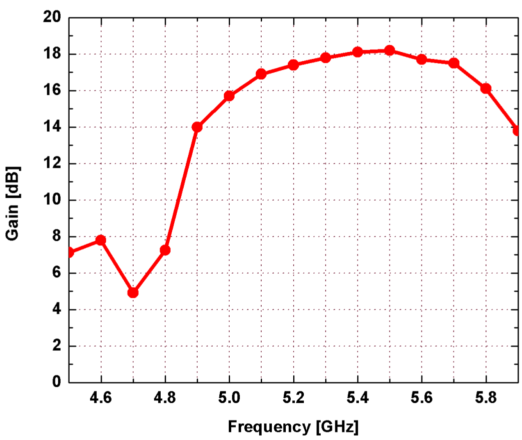


Fig. 6. The gain over the frequency band.

The obtained results have been summarized in the following table:

Table 3. The summary of the simulation results

Parameters	Simulation Results
Frequency range	4.5 - 5.9 GHz
Peak gain	18.2 dB (at 5.5 GHz)

3. Fabrication and measurement

3.1. Fabrication of the Array

After optimizing, a prototype has been fabricated (as shown in Fig. 7) in order to validate the simulation results. It is then measured by using the Vector Network Analyzer (VNA) and Near Field System.

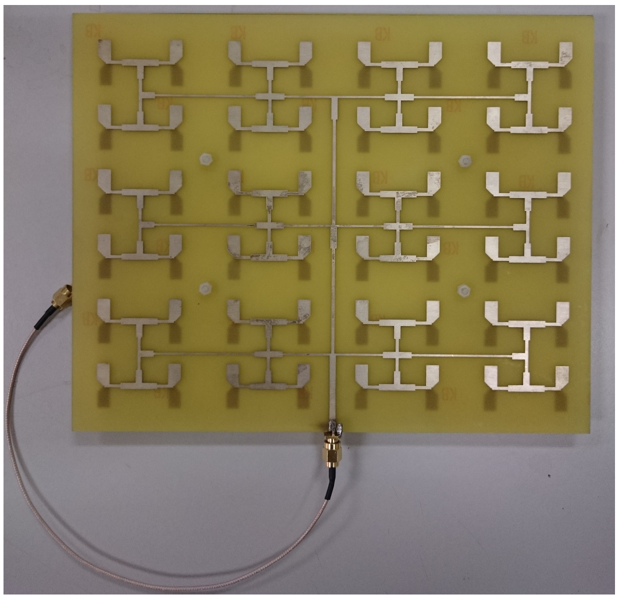


Fig. 7. The fabricated antenna sample.

3.2. Measurement data

The measurement data of the prototype was compared with the simulation results as given in Fig. 8. It is clearly that good agreement between measurement and simulation has been obtained.

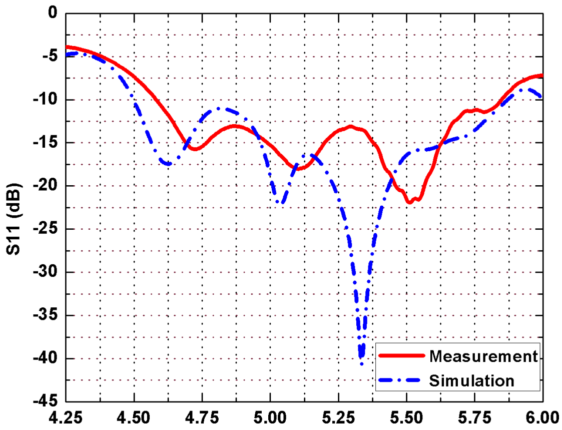


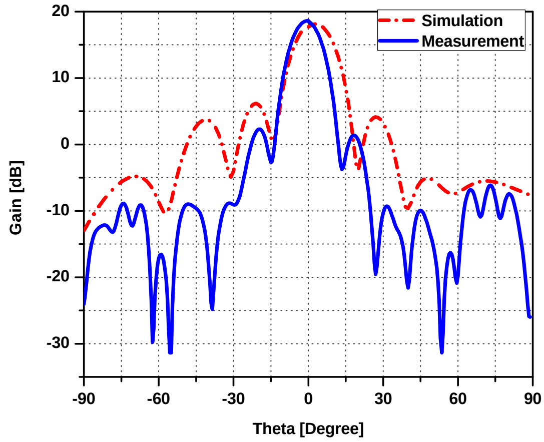
Fig. 8. Comparison between the simulation and measurement results.

Additionally, the measured radiation patterns in E and H planes have also been demonstrated and compared with the simulation in Fig. 9.

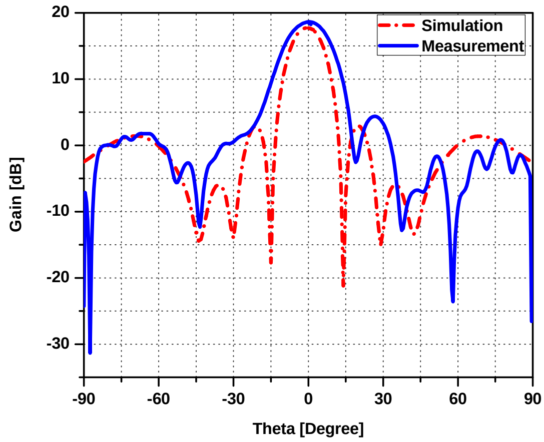
Table 4. Comparison between simulation and measurement data

Parameters	Simulation	Measurement
Bandwidth at RL=-10 dB	1400 MHz (4.5 - 5.9 GHz)	1300 MHz (4.6 - 5.9 GHz)
Peak gain at 5.5 GHz	18.2 dBi	18.64 dBi
Side lobe level	-14.4 dB	- 16.32 dB

It is noticed that the measurement results in terms of the return loss and the radiation pattern meet very well with the simulation data. The measured HPBW of E-plane of the proposed array is 12.5^o, while at the H-plane it is 17.8^o. The measured peak gain at 5.5 GHz is 18.64 dBi compared to 18.2 dBi in the simulation. In addition, the side lobe level (SLL) in measurement result is about -16.32 dB which is much better than the simulation one, with -14.4 dB of SLL. Therefore, it is evident that the array antenna



(a) E- plane



(b) H - plane

Fig. 9. Comparison of the radiation pattern of the array.

has high gain with pencil beam which meets the requirements of IEEE 802.11ac.

4. Conclusions

This paper has proposed a new design of planar dipole array antenna. The array antenna comprising of $4 \times 4 \times 3$ elements has been constructed from the FR4-epoxy substrate. Good agreements between measurement and simulation have been obtained. It can be a good product for Wi-Fi ac outdoor access point (AP) routers.

Acknowledgements

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