A novel fan beam and high gain antenna array for outdoor applications

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ABSTRACT

This paper introduces a novel high gain and wideband antenna array at 5 GHz for outdoor applications. The proposed array consists of a 2×9 elements planar array and a reflector. This antenna has a gain peak of 15.7 dBi and a bandwidth of 2 GHz from 4.0 GHz to 6.0 GHz. The angle coverage of 240° in the azimuth plane with gain 2 dBi higher. The total dimension of the antenna array is 31.5×13.4×1.2 cm^3 which is fabricated on RO4003C substrate. The antenna has been fabricated and measured, the measurement and the simulation results are in good agreement.

Keywords: Planar array; Printed dipole-Yagi antenna; Fan beam; Series feed.

1. INTRODUCTION

Nowadays, Wi-Fi technology is operated based on IEEE 802n/ac standard at 5 GHz, Wireless local area networks (WLANs), Personal area network (PAN) and Dedicated short range communication (DSRC-) [1, 2]. Outdoor access points request integrated antenna installed on the wall or public area for serving activities in urban area [3, 4]. Thus, it is a desirable to design a compact, low cost, high gain and broadband antenna. In order to transmit broadcast signal, omnidirectional antenna system is necessary. However, the gain of omnidirectional antenna is only 2 dBi, it limits the coverage area of access points. There are several methods to improve the coverage area of outdoor access points such as: high gain and broadband omnidirectional antenna [5-8], MIMO array [9] and smart antenna [10, 11]. For all above presented papers, high gain and wide-angle radiation antennas are attractive solutions for Wi-Fi outdoor access points.

In this paper, we propose a compact, high gain, broadband and wide horizontal angular coverage antenna array is presented. The antenna elements are designed based on printed Yagi antenna. The proposed fan-beam antenna array achieved the maximum gain of 15.7 dBi, fractional bandwidth of 40% at 5 GHz and HPBW of 240°.

This paper consists of three sections. Section 2 describes the basic concept and design principles of antenna element and antenna array. In addition, the simulated and measured results are compared in this section. Some conclusions and discussions are presented on section 3.

2. DESIGN OF THE NOVEL WIDE FAN BEAM AND HIGH GAIN ANTENNA

2.1. Printed Yagi antenna element

The proposed printed Yagi (PY) antenna is inspired by dipole antenna with a balun in [12]. Based on the wire balun of W.Roberts, a printed balun is designed in this work. The structure of the antenna element consists of a half-wavelength printed dipole antenna and two directors presented in figure 1. Two radiated arms of dipole antenna are curved to reduce the size of element. The distance between the directors and the radiation arms is usually (0,1 ÷ 0,35)λ_o [13]. The antenna using Rogers 4003C substrate with a dielectric constant of 3.55 and thickness of 0.8 mm. A survey of the element antenna with the number of different directors (n = 0 ÷ 9) is simulated based on CST (Computer Simulation Technology) software. The characteristics of a designed Yagi antenna remain unchanged the properties of a conventional Yagi antenna. As the number of directors increases, the gain also increases. The optimal parameter set of the designed Yagi antenna varies slightly when increasing the number of directors (i = 1, 2, 3…n). As n is bigger than two, the gain increases, but the size of the height of the antenna also increases. Because of desired compact antenna, the work chosen two directors for this design called PY2. The parameter values of the PY2 are selected based on simulation to optimize gain at 5 GHz shown in table 1. The PY2 antenna achieves a gain of 7.64 dBi at 5 GHz, a bandwidth of 500 MHz, and a radiation efficiency of over 96.2% is obtained. The antenna element has dimensions of 29×37×0.8 mm^3. Simulated results of S11 and the antenna's two-dimensional radiation pattern are presented in figure 2.

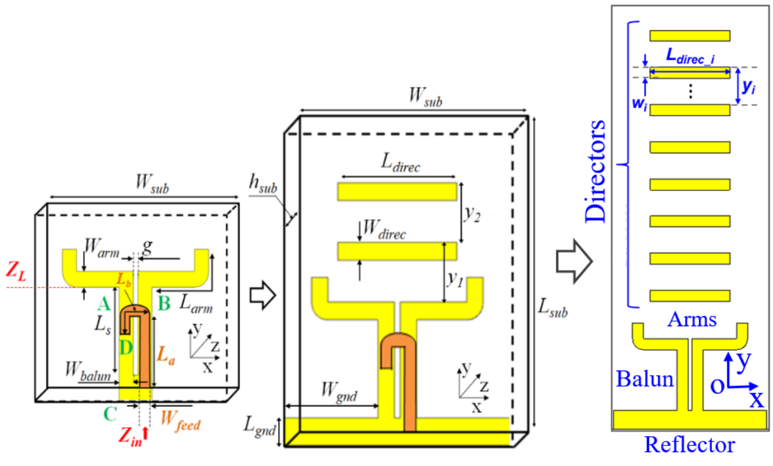

Figure 1. *Printed dipole with integrated J-balun; the proposed PY2 and PYn antenna.*

Table 1. *Parameters of PY2 in 5 GHz; unit mm.*

.Arms		Directors		Balun	
Parameter	Value	Parameter	Value	Parameter	Value
L_{arm}	11.4	L_{direc}	15	W_{balun}	2.1
W_{arm}	2.1	W_{direc}	2.1	L_a	10.1
L_s	8	y_1	7 (0.15×λ_g)	L_b	8.0
g	0.7	y_2	7 (0.15×λ_g)	W_{feed}	2.1
h_{sub}	0.8	L_{gnd}	3.5		
L_{sub}	37	W_{gnd}	12		
W_{sub}	29				

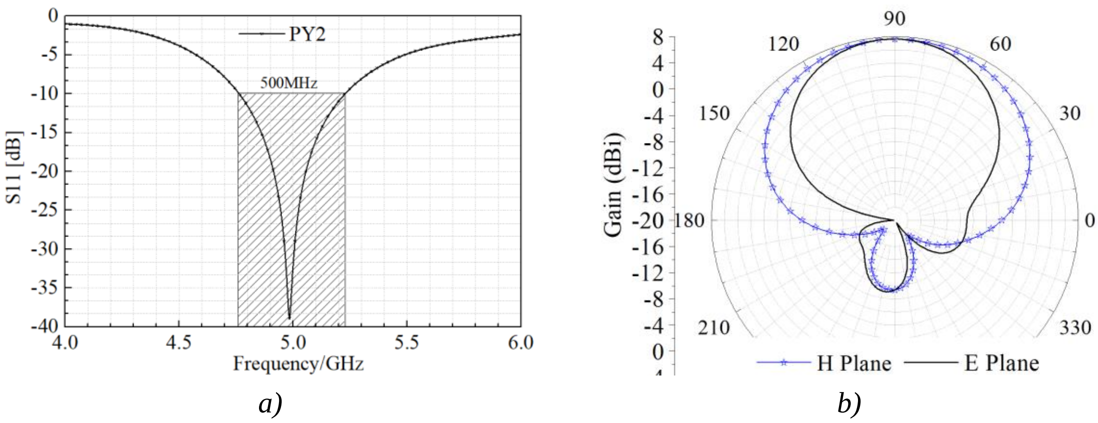

Figure 2. *The simulated reflection coefficient (a) and 2D radiation pattern of PY2 (b).*

2.2. Feeding network design

This work proposes an array antenna consisting of two sub-arrays, each of which consists of nine PY2 elements arranged as a uniform linear array along the *x*- axis. The series feeding network in the sub-array is shown in figure 3. The radiation pattern of the array is formed based on the radiation pattern of the element antenna and the array factor shown in formula (1) [14]:

$$AF = \sum_{n=1}^{N} e^{j(n-1)(kdcos\theta+\beta)} \tag{1}$$

where, k is the wave propagation coefficient, $d \approx 0.583\lambda$ is the distance between the elements and $\beta = 2\pi$ is the phase difference between the elements in the sub-array. N is the number of elements in the subarray (N=9). The sub-array has a total size of 315×60×0.8 mm^3.

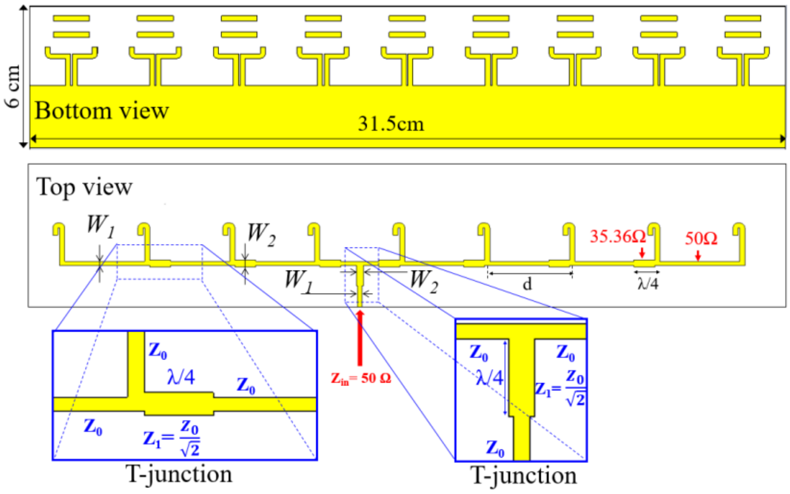

Figure 3. *The half of feed network model with T-Junction.*

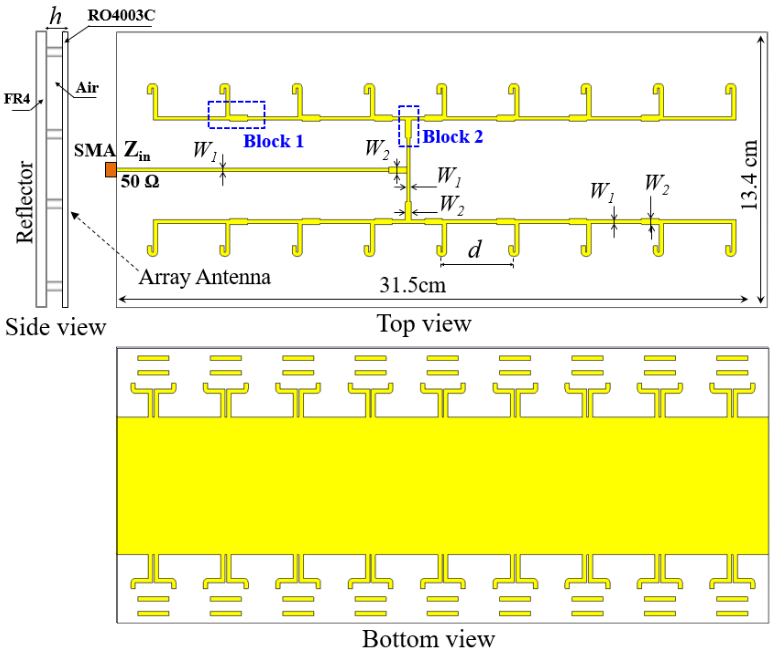

Figure 4. *Geometry of the proposed array antenna.*

We consider the input impedance to the sub-array is $Z_{in} = Z_0 = 50\ \Omega$. According to the principle of a T-shaped power divider, the impedance characteristic Z_1 is 35.36 Ω, with a length of quarter wavelength (λ/4). Base on optimization process, the transmission line widths have the following values W_1 = 1.75 mm, W_2 = 2.9 mm and d = 35 mm. The sub-array consists of 9 × 1 elements in series to create a radiation pattern with a gain of 14.2 dBi. To improve the gain for the sub-array, we added a reflector placed h = 12.17 mm from the array. The gain of sub-array with reflection plane increases to 15.3 dBi. A combined two parallel sub-arrays are shown in figure 4. The proposed antenna array with the reflecting plane has a total size of 31.5×13.4×1.217 cm^3.

2.3. Comparison of the simulated and the measured results

The antenna array is fabricated and tested by VNA machine as shown in figure 5. The S11 measurement results are quite similar to the simulated results with a bandwidth of 2 GHz (-10 dB) at 5 GHz (figure 6). The two-dimensional radiation patterns of the array antenna have simulation results presented in figure 7. The results indicate that the maximum gain of 15.7 dBi have been acquired at 5 GHz. The width in the direction of the fan beam-width a gain greater than 2 dBi (equal to the gain of omnidirectional antenna) has a wide coverage angle of 240°. Measurement of the three-dimensional radiation pattern of the antenna array with efficiency is 85.8% is shown in figure 8. Both measurement and simulation results are well fit together.

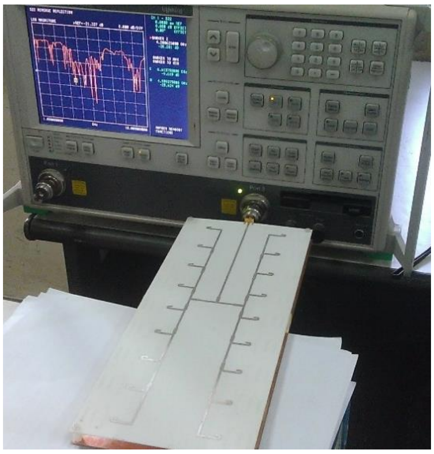

Figure 5. *The antenna prototype.*

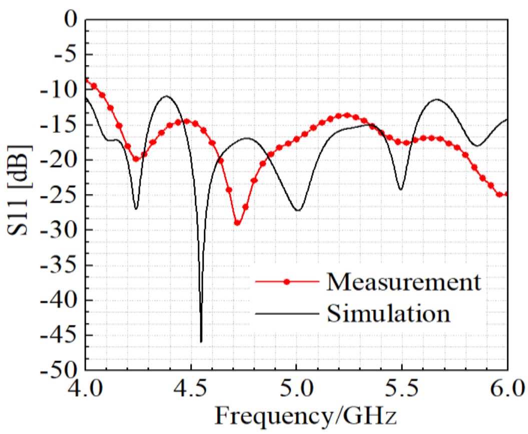

Figure 6. *The simulated and measured reflection coefficients of array antenna.*

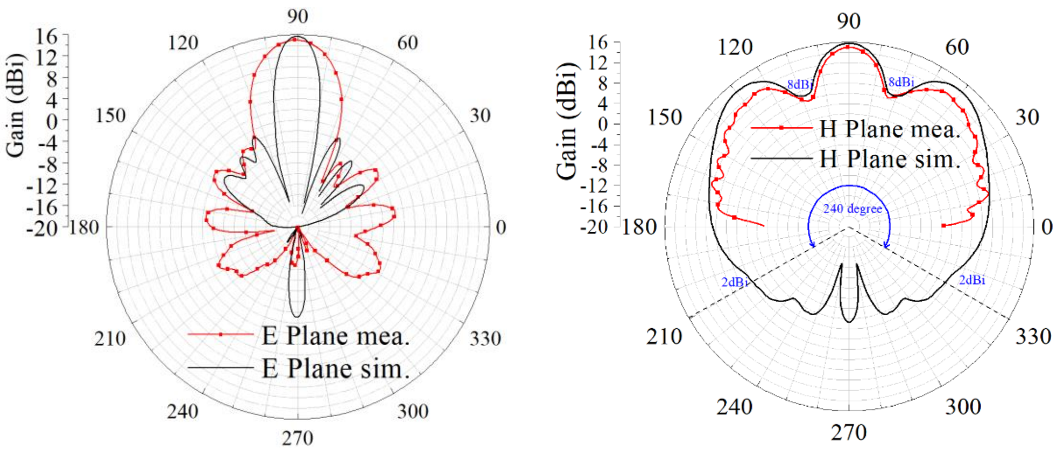

Figure 7. *The simulated and measured radiation pattern of array antenna in E and H plane.*

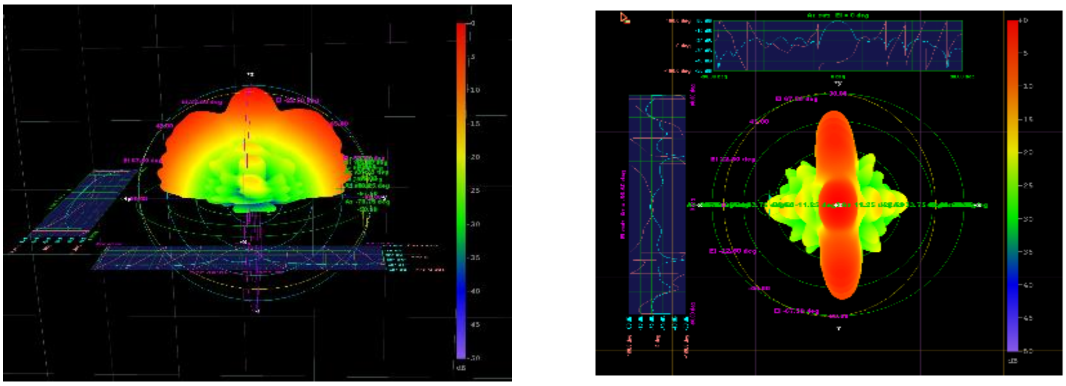

Figure 8. *3D radiation pattern measurement results of the array antenna.*

Table 2 compares the performance of the proposed array antenna and several previous works. It is found that the realized peak gain and bandwidth of the proposed antenna are the highest. Though my proposal has a significantly wider beam-width than the reference [15, 16] . However, the antenna beam width of 240° is smaller than the angle of the antenna in [17]. In terms of the antenna profile, the antenna has an unshakeable for real-world deployment.

Table 2. *Comparison to the other related works.*

Parameter		[15] 2017	[16] 2018	[17] 2020	Proposed
$Gain_{max}$(dBi)		14.5	10	11.1	15.7
Bandwidth (%)		2.4	30.76	3	40
Beamwidth (°)	E-plane	8.3	7	-	11
	H-plane	60	120	>256.7	240
Elements		1×10	1×8	1×8	2×9

3. CONCLUSIONS

The array antenna has been fabricated with the highlight of high gain of 15.7 dBi, 2 GHz bandwidth and angular radiation in azimuth of 240°. The proposed array antenna is suitable for broadcast communication and streaming video for outdoor systems. The array antenna is designed to install into radio equipment for the wireless system. There is a good performance as array antenna model is tested outdoors.

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TÓM TẮT

Anten mảng búp sóng hình dải quạt rộng, độ lợi cao cho các ứng dụng ngoài trời

Bài báo trình bày anten mảng mới độ lợi cao, băng thông rộng ứng dụng cho các thiết bị vô tuyến ngoài trời ở tần số trung tâm 5 GHz. Mảng anten được đề xuất gồm có mảng phẳng 2×9 phần tử và một mặt phản xạ. Anten đề xuất có độ lợi cực đại là 15.7 dBi và độ rộng băng thông là 2 GHz từ 4.0 GHz đến 6.0 GHz ứng với S11 nhỏ hơn -10 dB. Độ rộng búp sóng theo phương dải quạt là 240° ứng với độ lợi lớn hơn 2 dBi. Kích thước tổng của anten là 31.5×13.4×1.2 cm^3 và được chế tạo từ chất nền RO4003C. Anten đã được chế tạo và đo kiểm, kết quả đo tương đồng với kết quả mô phỏng.

Từ khóa: Anten mảng; Anten lưỡng cực dẫn xạ mạch in; Búp sóng hình dải quạt; Mạng tiếp điện nối tiếp.