A Novel Compact High-Gain Printed Quasi-Yagi Antenna and its Harmonic-Suppression Array

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Abstract **─** In this paper, a novel compact printed quasi-Yagi antenna with a high gain of 8.39 dB is presented, and its binary antenna array with harmonic suppression is explored. The proposed antenna fed by a 100 Ohm coplanar stripline (CPS) achieves a 14.32 % relative bandwidth for a -10 dB reflection coefficient. The stepped impedance resonator (SIR) structure is adopted to suppress the harmonic radiations in the binary array, which is fed by a 50 Ohm coplanar waveguide (CPW). Due to its single-sided structure, this high gain antenna element and the binary array have many advantages, such as easy fabrication, compactness, low profile, and low cost. The antenna and array can be widely applied in wireless communication systems, especially in wireless power transmission (WPT) system.

Index Terms - Binary array, compact high-gain antenna, harmonic suppression, and Quasi-Yagi antenna.

I. INTRODUCTION

Wireless power transmission via microwave has attracted significant attention in the past [1]. The rectenna is a key component in WPT and has been used to provide direct current (DC) power for radio frequency identification (RFID) tags, wireless sensor servers, and clock batteries [2]. Generally, a typical rectenna consists of an antenna to collect incoming RF power, a matching circuit, an input low-pass filter (LPF) to suppress unwanted higher harmonics generated by the rectifying diode, one or more rectifying diodes, an output DC pass filter, and a resistive load. However, the input LPF could be saved by the antenna with harmonic suppression, which also decreases the rectenna size and cost. Thus a high gain antenna with harmonic suppression is essential to improve the performance of rectenna and the total conversion efficiency of WPT.

Yagi-Uda antenna is a widely used high gain antenna with end fire radiation, which consists of a reflector, a driven element, and one or more directors. In recent years, printed quasi-Yagi antenna has been exhaustively analyzed and experimentally researched. According to the driven element form, the existing quasi-Yagi antenna can be divided into microstrip patch form [3, 4], double-sided dipole form [5, 6] and single-sided dipole form [7, 8]. The microstrip patch form is usually fed by a coaxial probe [9], while the double-sided dipole form often adopts a truncated ground plane as a reflector whose length could not be well optimized. The single-sided form is mostly fed by a CPS [8] or coplanar waveguide (CPW) [10], which is easy-fabricated and does not need a large ground plane on the other side of substrate.

In this paper, we present not only the design and measurements of a high gain and compact printed quasi-Yagi antenna element, but also the design and simulation of its binary antenna array. Since a 50 Ohm CPW line can be achieved directly by paralleling two 100 Ohm CPS lines together, the proposed antenna is fed by a 100 Ohm CPS, which aims to build a CPW-fed two-element antenna array in the next step. The antenna achieves a high gain of 7.96 dB, a 9.6 dB front-to-back ratio, efficiency of 85.1 % at 5.8 GHz, and a 14.32 % relative bandwidth for a -10 dB reflection coefficient. The binary array has maximum gain of 12.1 dB at 5.8 GHz and

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suppresses the harmonics very well. This compact antenna and its array are simply fabricated and easily integrated with other solid-state components in WPT system.

II. ANTENNA ELEMENT DESIGN

Figure 1 shows the schematic diagram of the high gain and compact printed quasi-Yagi antenna. The antenna utilizes five director elements and one reflector in order to maximize beam directivity, and is printed on a 0.5 mm thick Rogers RO4003C substrate (permittivity ε_r = 3.38, loss tangent tanδ = 0.0027). Both the convenience of constructing a feed network for antenna array and the high characteristic impedance of the CPS prompt us to use a 100 Ohm CPS as feed line. The gap of the CPS is 0.2 mm considering the resolution of the etching process. The driven element is a wide printed half wavelength dipole antenna.

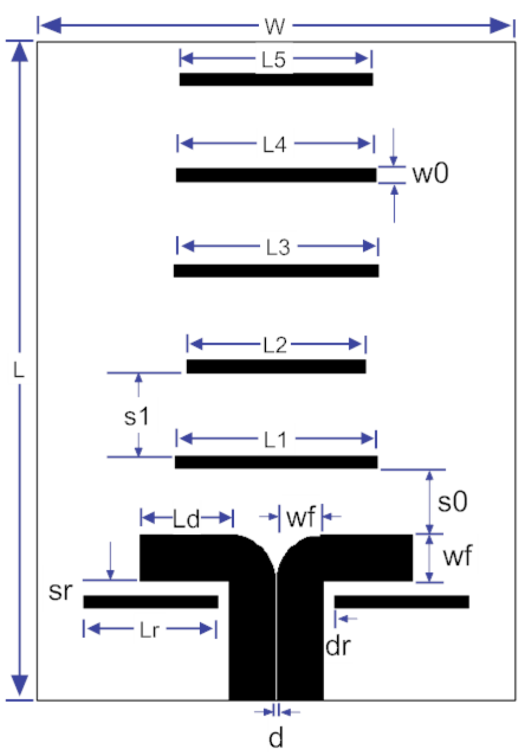

Fig. 1. Schematic diagram of the proposed quasi-Yagi antenna.

A pair of symmetrical reflector is placed under the dipole. Five directors are placed above the dipole. And the spacing between every two adjacent directors is the same. Additionally, the width of the reflector and directors is identical.

It is important to note that the reflectors are placed very close to the driven element in the proposed antenna. The traditional distance between the reflector and the driven element is 0.15λ~0.25λ, where λ is the wavelength of operating frequency. The wavelength can be calculated by,

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{reff}}} \tag{1}$$

where λ_0 is the wavelength in vacuum and ε_{reff} is the effective dielectric constant, which can be calculated by

$$\varepsilon_{reff} = 1 + \frac{\varepsilon_r - 1}{2} \cdot \frac{K(k')}{K(k)} \cdot \frac{K(k_1)}{K(k_1')} . \tag{2}$$

The detailed derivation is introduced in [8], thus we can obtain the values of ε_{reff} and λ_g at 5.8 GHz, which are 1.43 and 43.29 mm, respectively. The optimized distance between the reflector and the driven element in our proposed antenna is only 0.03 λ (1.3 mm), which is much smaller than the traditional one. Furthermore, when compared with the reflector of the truncated ground plane, the utilization of a pair of independent reflectors behind the driven dipole not only enhances the pattern performance but also provides more design flexibility. The proposed antenna is simulated by the transient solver in CST Microwave Studio. The optimized parameters are given in Table 1.

Table 1: Design parameters of the optimized antenna.

Parameter	Value (mm)	Parameter	Value (mm)
L	55	s0	5.6
W	40	s1	7
wf	3.8	L1	16.9
d	0.2	L2	15
Ld	7.5	L3	17
Lr	11.2	L4	16.7
dr	1	L5	16.2
sr	1.3	w0	1

III. SIMULATED AND MEASURED RESULTS OF ANTENNA ELEMENT

The simulated and measured S_{11} (dB) results of the proposed antenna are shown in Fig. 2. The antenna was measured by using the Agilent E8363C network analyzer.

As shown in Fig. 2, the measured -10 dB impedance bandwidth is 5.25 GHz - 6.06 GHz (relative bandwidth 14.32%). The simulated bandwidth is 5.08 GHz - 6.02 GHz (relative bandwidth 16.94 %). The measured results agree well with the simulated results generally.

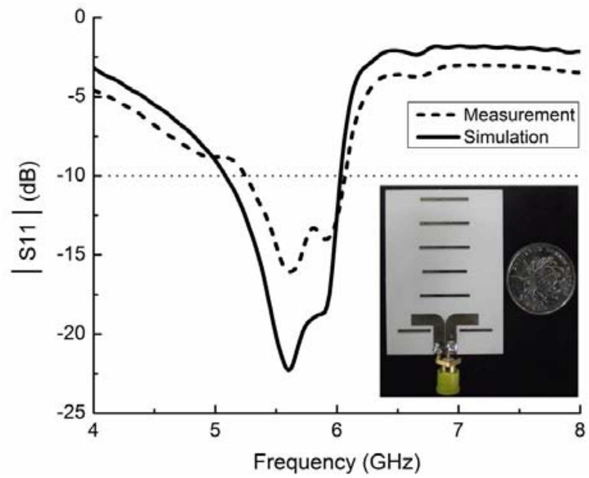

Fig. 2. Simulated and measured reflection coefficient magnitude of the proposed antenna.

The radiation patterns at 5.8 GHz for the E-plane and H-plane are shown in Figs. 3 and 4, respectively. A good agreement is observed between the simulated and measured results, for both the E- and H-plane patterns. The measured half power beam width (HPBW) is 46.7 degree along the E-plane and 57.4 degree along the H-plane.

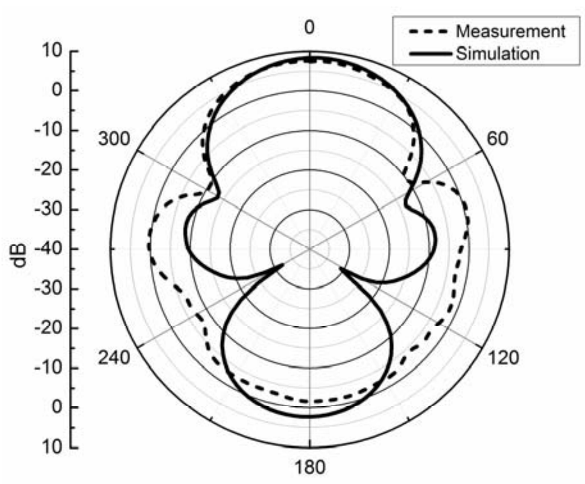

Fig. 3. Simulated and measured E-plane of the proposed antenna at 5.8 GHz.

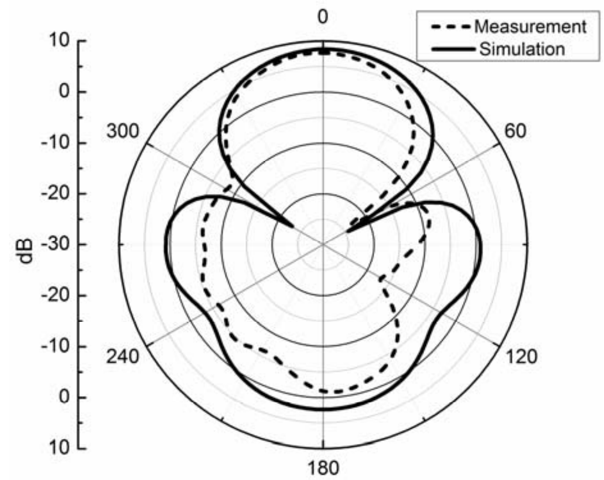

Fig. 4. Simulated and measured H-plane of the proposed antenna at 5.8 GHz.

Figure 5 illustrates the simulated and measured peak gain of the proposed antenna. The measured maximal absolute peak gain value in the main beam is 8.39 dB at 6 GHz, while the simulated value is 9.38 dB. At 5.8 GHz, the measured gain is 7.96 dB, which is approximately 2 dB higher than the results in [8]. Additionally, the gain varies much against frequency.

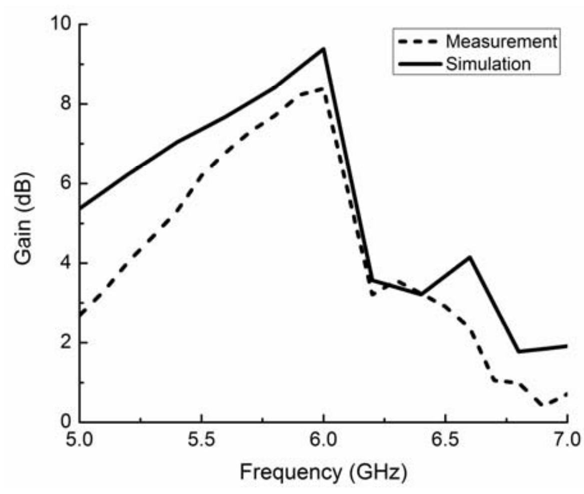

Fig. 5. Simulated and measured peak gain variation against frequency for the proposed antenna.

IV. DESIGN AND SIMULATION OF THE BINARY ARRAY

From the sections above, the compact quasi-Yagi antenna element can achieve a high gain of

7.96 dB at 5.8 GHz. To improve the gain, we can build a 50 Ohm CPW-fed two-element antenna array. A branch structure is adopted as the power divider for antenna feeding, in which a 50 Ohm CPW line is divided into two 100 Ohm CPS lines. However, due to the symmetry of the branch structure, the output signals are equal in magnitude but have a phase difference of 180 degrees. Therefore, a half wavelength CPS line is added to the right arm of the branch structure to ensure the same phase of the output signals.

We used the SIR structure on the ground of CPW line to suppress the harmonics. The analysis of the SIR can be found in [12]. Figure 6 shows the schematic diagram of the binary quasi-Yagi antenna array, which is simulated by the transient solver in CST Microwave Studio. The optimized parameters of the binary array are given in Table 2.

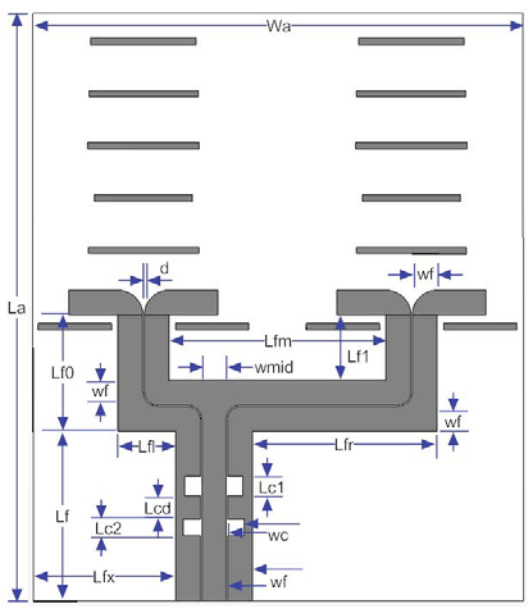

Fig. 6. Schematic diagram of the binary quasi-Yagi antenna array.

Table 2: Design parameters of the optimized array.

Parameter	Value (mm)	Parameter	Value (mm)
La	90	Lfm	33.2
Wa	75	Lfl	8.8
wf	3.8	Lfr	28.3
d	0.2	Lc1	3
Lf0	17.8	Lc2	2.6
Lf1	10	Lcd	3.5
Lf	26	wc	2.6
Lfx	21.8	wmid	33.2

As shown in Fig. 7, the simulated -10 dB impedance bandwidth is 5.12 GHz - 6.05 GHz (relative bandwidth 16.65%). The reflection coefficient on the second harmonic (11.6 GHz) is -0.45 dB and the reflection coefficient on the third harmonic (17.4 GHz) is -0.97 dB, which means that the radiations at the harmonic frequencies are well suppressed.

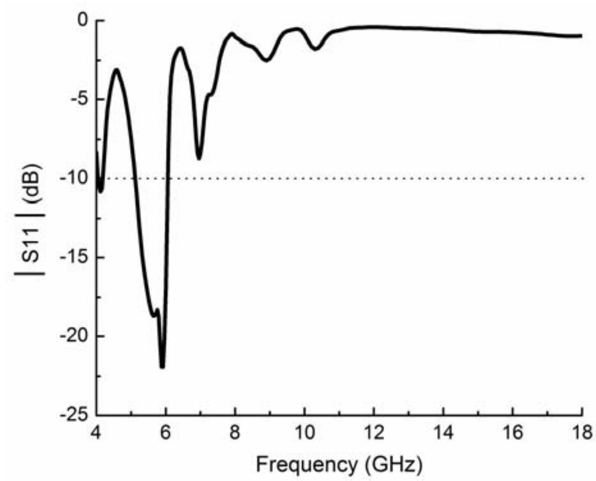

Fig. 7. Simulated reflection coefficient magnitude of the antenna array.

Figure 8 illustrates the simulated E-plane and H-plane at 5.8 GHz. The HPBW was 30.2 degree along the E-plane and 55.9 degree along the H-plane. Compared with the quasi-Yagi antenna element, the HPBW of the binary array in the E-plane is reduced by 16.5 degrees, while the HPBW in H-plane decreases only 1.5 degrees. The simulated peak gain at 5.8 GHz is 12.1 dB, which is 4.14 dB higher than the measured gain of single antenna element. The side lobe level is -10.5 dB in the E-plane and -7.2 dB in the H-plane.

V. CONCLUSION

This paper presents a novel compact printed quasi-Yagi antenna with a high gain of 8.39 dB. The proposed antenna also offers flexibility in designing reflector, instead of employing a truncated ground plane. Furthermore, the very small distance between the reflector and the driven element guarantees a compact structure. The binary array based on the proposed antenna is designed and simulated, which has high gain of 12.1 dB at 5.8 GHz. To have suppression at both the second and third harmonic frequencies, the

SIR structure is adopted. This high gain antenna and its array have advantages of easy fabrication, compactness, low profile and low cost, owing to its single-sided structure. Therefore, they can be widely applied in wireless communication systems, especially in WPT system.

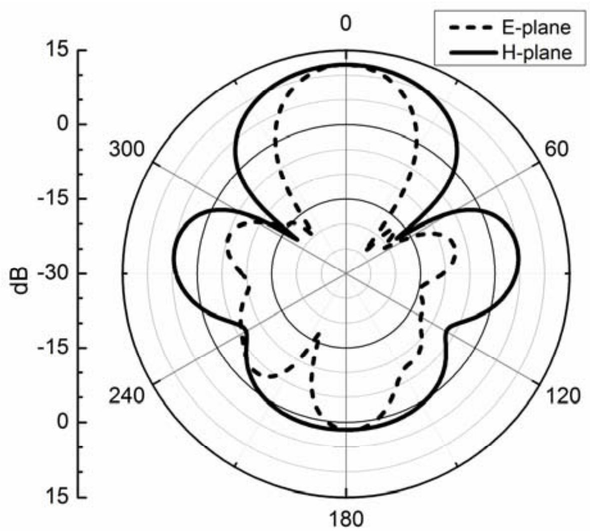

Fig. 8. Simulated E- and H-planes of the antenna array at 5.8 GHz.

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