Rotated Stacked Yagi Antenna with Circular Polarization for IoT Applications

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Abstract **─** This letter proposes a rotated stacked Yagi antenna with high directivity and circular polarization. The proposed antenna consists of three elements with a rotation angle and different lengths: a director, a reflector, and a driven element connected to the coaxial feeder. The coaxial feeding is connected to the driven element of the proposed antenna via a LC-balun, and the others are coupled with the driven element. Each stacked element with different lengths is equally rotated at an angle of 60° with respect to the lower element so that the dipole array antenna forms a high directive circular polarization. The size of the proposed antenna is $0.49\lambda_0 \times 0.49\lambda_0 \times 0.17\lambda_0$ at 2.45 GHz and achieved a 10 dB impedance bandwidth of 6.3%, a 3 dB axial ratio bandwidth of 8%, and a peak gain of 4.3 dBic.

Index Terms **─** Array, circular polarization, dipole antennas, IoT, rotated stacked, Yagi antenna.

I. INTRODUCTION

Recently, the number of wireless communications for automobiles, unmanned aerial vehicles (UAVs), internet of things (IoT), and health-care sensors is increasing. In particular, communication performance of the IoT sensor module with a linear polarized antenna depends on multi-path effect and polarization loss factor. The circular polarization (CP) antenna can receive a signal of a linearly polarized antenna disposed in any direction. To reduce the polarization loss of the multi-path effect of the linear polarization (LP) antennas used on these smart devices, several studies on achieving circular polarization are being conducted [1]-[13].

Generally, in a single-fed microstrip patch antenna, the CP is formed by cutting the patch edge of the antenna [1]-[3] or by disposing the feeding point on the diagonal line of the patch [4]. Additionally, inserting a U or L-shaped slot into a patch [5]-[7] is one of the methods to create the CP. However, the problem with these antennas is that the area is large owing to the space needed to place the patches of the antennas. On the other hand, for multi-fed antennas, the CP can be obtained by a feeding network that generates phase differences [8]-[10]. In [11], each feeding point was provided the signals 0°, 120°, 240° Those phase differences achieved CP. In addition, studies have conducted using meta-material or ring antenna structures [12]-[13]. However, these methods to generate CP need complex feeding networks, including hybrid couplers or splitters. In this paper, we propose a simple structure antenna that can achieve a high directive CP antenna with a single feed. The stacked structure produces not only circular polarization but also a high degree of directivity, which makes it suitable for IoT applications at 2.45 GHz.

II. ANTENNA CONFIGURATION AND ANALYSIS

Figure 1 shows the configuration and design parameters of the proposed rotated stacked Yagi antenna with circular polarization. The proposed antenna consists of three elements with a rotation angle and a spacing distance as shown in Fig. 1 (a). In Fig. 1 (b), the proposed antenna obtains the directivity of the antenna by the length difference of the three elements and the stacked structure as a Yagi antenna. Due to the difference in length of the three elements constituting the proposed antenna, each of the elements serves as a director that forms the directivity of the antenna, a driven element that directly connects to the coaxial feed point, and a reflector that gets rid of the backside radiation. In addition, each element of the proposed antenna is arranged with a rotation angle of 60° with respect to the lower elements to achieve circular polarization. In this case, in order to realize a phase difference of 180 degrees with two elements, they are arranged at a rotation angle of 90 degrees (180/2) between antenna elements. Thus, when CP is typically implemented in three elements, it is designed to have a rotation angle of 60 degrees (180/3) between antenna elements. The operating frequency of the proposed antenna depends mainly on the length of the driven element. Therefore, the performance of the proposed antenna is determined by the spacing distance and the rotation angle. Figure 1 (c) shows an expanded

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view of the antenna input with the LC-balun. The input of the antenna is connected to the signal of the coaxial cable through the LC-balun. Figures 1 (d) and 1 (e) represent the top and side views of the prototype of proposed antenna including three antenna supports.

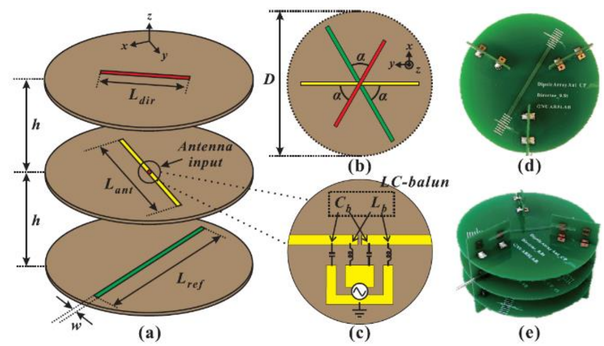

Fig. 1. Geometry of the proposed rotated stacked Yagi antenna configuration and its prototype: (a) perspective view, (b) top view, (c) expanded view of antenna input, (d) top view of fabricated antenna prototype, and (e) side view of fabricated antenna prototype.

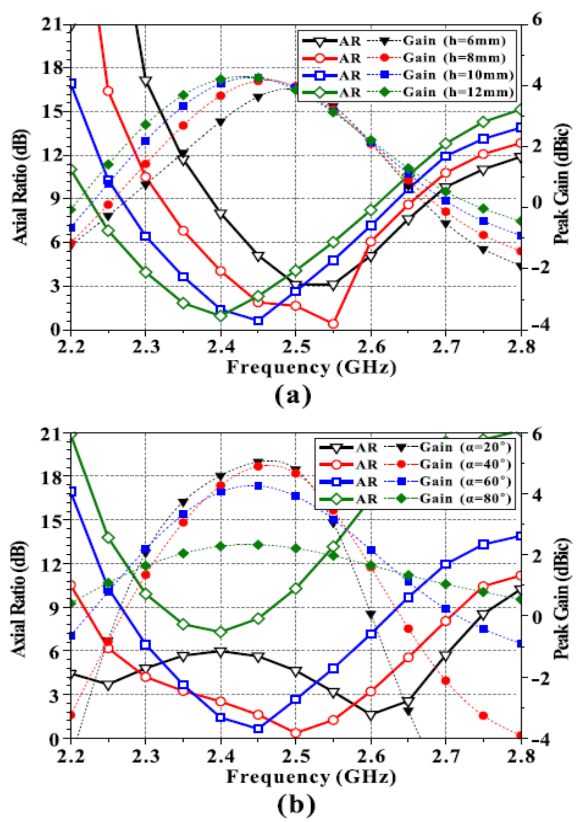

Fig. 2. Simulated axial ratio and peak gains of the proposed antenna with regard to the design parameters: (a) spacing distance, h, and (b) rotation angle, α.

Figure 2 shows the results of parameter studies for variation of the spacing distance and angle. The index on the left represents axial-ratio, and the index on the right represents the peak gain. As the spacing distance increases in Fig. 2 (a), where the rotation angle is 60 degrees, the frequency at which circular polarization of the proposed antenna is formed decreases, while the peak gain of the proposed antenna increases. Figure 2 (b) shows the result of the axial ratio and peak gain according to the angle variation. When the rotation angle of the elements is 60°, the CP of the proposed antenna is most accurately obtained. In Fig. 2 (b) with the same distance of 10 mm, the coupling effect from the radiator decreases as the rotation angle increases. As a result, the larger the rotation angle, the smaller the gain of the antenna. Therefore, to obtain circular polarization, the proposed antenna must have appropriate spacing distance and an appropriate rotation angle. The process of forming the circular polarization by the proposed antenna is shown in Fig. 3, which depicts the E-field at the point 30 mm away from the driven element of the proposed antenna on the *z*-axis. The figure confirms that the direction of the E-field vector is rotated according to the variation of phase.

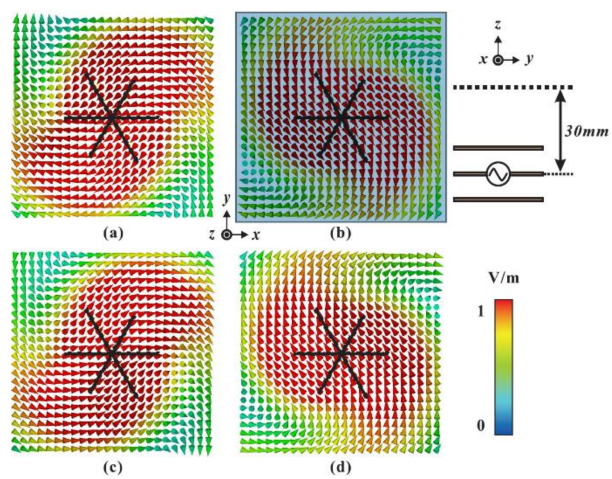

Fig. 3. E-field distributuons at *xy* plane of 30mm away from the driven element in the proposed antenna with regard to the phase variation: (a) 0°, (b) 90°, (c) 180°, and (d) 270°

III. RESULTS AND DISCUSSIONS

For the experimental verification, the proposed rotated stacked antenna was designed and implemented on a FR-4, the most representative substrate with a thickness of 0.8 mm, a dielectric constant ε_r = 4.5, a loss tangent δ = 0.02, and a copper thickness of 18 um. The parameters of the designed antenna are L_{dir}= 43.1 mm, L_{ant} = 46.0 mm, L_{ref} = 50.9 mm, w = 1.41 mm, h = 9.8mm, α = 60°, D = 58 mm, L_b = 3.3 nH, and C_b = 1.2pF.

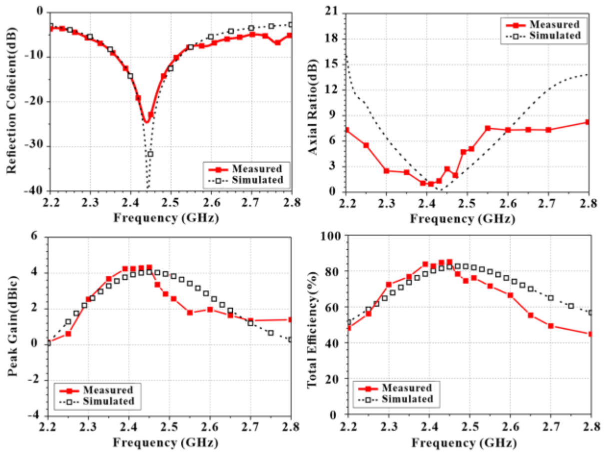

Fig. 4. Simulated and measured results of proposed antenna according to frequency: (a) reflection coefficients, (b) axial ratio, (c) peak gain, and (d) total efficiency

Figure 4 presents the simulated and measured results of a fabricated prototype antenna. The simulation results are using a full-wave electromagnetic tool (CST Microwave Studio 2018). Figure 4 (a) shows the simulated and measured reflection coefficients of the proposed antenna, and the 10 dB impedance bandwidth is approximately 6.3%. The axial ratio of the proposed antenna according to frequency is shown in Fig. 4 (b). The proposed antenna has approximately 8% of the 3 dB axial ratio bandwidth performance around 2.45 GHz. The peak gain and total efficiencies of the proposed antenna at 2.45 GHz are approximately 4.25 dBic and 85% in Figs. 4 (c) and 4 (d), respectively. The simulated and measured results indicated that the proposed antenna has a resonance characteristic at 2.45 GHz where it supported various IoT networks.

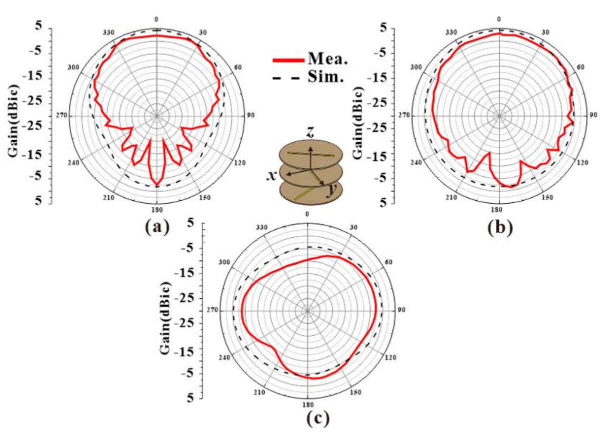

Fig. 5. Simulated and measured radiation patterns of the proposed antenna at 2.45GHz: (a) *xy*-plane, (b) *yz*-plane, and (c) *xy*-plane.

Figure 5 describes the simulated and measured radiation patterns of the proposed antenna at 2.45 GHz in the *xz*, *yz*, and *xy* planes. The radiation pattern represents the high directivity of the proposed antenna for z-direction. Table 1 shows the characteristics between antennas for 2.45GHz. The proposed antenna can form a CP with a miniaturized size.

Table 1: Comparison with circular polarization antennas for 2.4GHz

	FRQ (GHz)	Peak Gain (dBic)	Electrical Size (λ_0)	AR. BW (%)	Imped. BW (%)
[3]	2.45	7.5	0.65 ×0.65 × 0.07	6.94	20.6
[7]	2.4	6.8	0.48 × 0.48 × 0.1	3.3	16
[9]	2.4	13.1	1.6 × 1.6 × 0.1	60	50
[10]	2.4	5.1	0.58 × 0.58 × 0.1	8.33	16.67
[12]	2.5	12	1.67 × 2.17 × 0.15	89	85
[13]	2.54	7	0.76 × 0.76 × 0.33	8.7	13.94
Prop.	2.45	4.3	0.49 × 0.49 × 0.17	7.93	6.27

IV. CONCLUSION

The study proposed a stacked dipole array antenna with a rotation angle for circular polarization. By applying a stacked structure with space distances, the proposed antenna is featured by directivity and circular polarization. The proposed antenna obtains a peak gain of 4.25 dBic and a performance of 8% of a 3 dB axial ratio bandwidth at 2.45 GHz. The proposed antenna covers the 2.45GHz band supporting the IoT network, and also has enough gain to be used in the actual communication environment, making it suitable for various IoT environments.

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