Isotropic Radiation From a Compact Planar Antenna Using Two Crossed Dipoles

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***Abstract*—This letter presents a compact printed isotropic-radiated planar antenna for 2.4-GHz wireless local area network (WLAN) applications. The antenna consists of two crossed curved dipoles printed on one side of a substrate. By adjusting the lengths of the two crossed curved dipoles, an isotropic radiation pattern is achieved in the whole band of 2.4–2.48 GHz. The proposed antenna is simulated, fabricated, and measured. The simulation results show that the difference between the maximum and the minimum of gains is smaller than 5 dB in the full space. In the measurement, the difference between the maximum and the minimum of gains is smaller than 6 dB over 97% of the full space. The reflection coefficient and gains are also tested and compared to the simulation results.**

***Index Terms*—Crossed curved dipoles, isotropic-radiated, planar antenna, radiation pattern.**

I. Introduction

Recently, wireless communication technology has attracted a significant amount of attention. Full spatial coverage radiation patterns are desired in practical applications, such as wireless access points (APs) and radio frequency identification (RFID) tags. Aiming to achieve the isotropic radiation patterns, some investigations were carried out in [1]–[8]. Three planar antennas were studied in [1]–[3]. Tridimensional antennas were also designed to achieve isotropic radiation patterns in [4] and [5]. For the same purpose, some researchers made use of array antennas [6]–[8]. Among these designs, the planar antenna [1]–[3] has the advantages of low profile, low cost, light weight, and easy fabrication. Combining a dipole mode and a loop mode on a printed circuit board to synthesize the isotropic pattern was proposed in [1], and the simulated peak gain deviation was 3.8 dB at 1 GHz. In [2], quasi-isotropic radiation pattern was achieved by using the inverted-F antenna made using a metal casing. The simulated directive gain deviation was 10.78 dB at 10.5 GHz. In [3], a passive UHF-band RFID tag antenna using two bent dipoles with a modified double T-matching network was proposed for near-isotropic radiation pattern. The gain deviation was smaller than 6 dB from 880 to 940 MHz.

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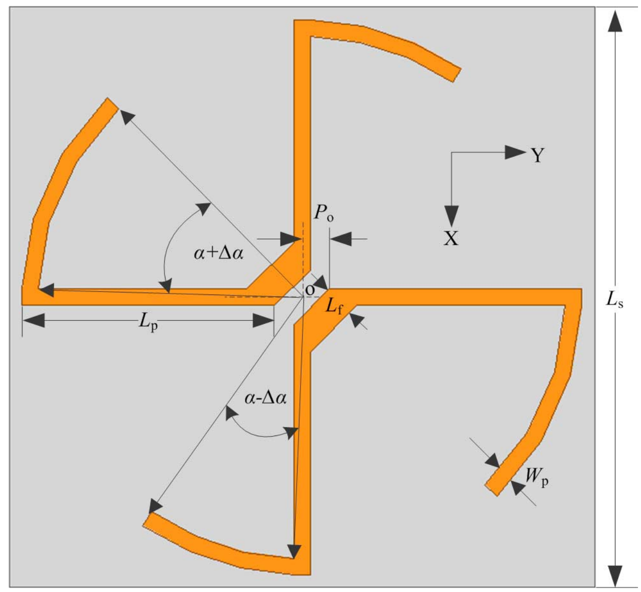

Fig. 1. Configuration of the proposed antenna.

This letter proposes a compact planar isotropic-radiated antenna using two crossed curved dipoles. By adjusting the lengths of two crossed curved dipoles, a complete spatial coverage could be achieved in the band of 2.4–2.48 GHz. The antenna structure is modeled and simulated, and key parameters of the antenna structure are analyzed and optimized. The reflection coefficient, the radiation pattern in a certain frequency, and the gain performance of the proposed antenna are measured and compared to the simulation results. The measured impedance bandwidth for $S_{11} < -10$ dB is 270 MHz, and the difference between the maximum and the minimum of gains is smaller than 6 dB over 97% of the full space.

II. Antenna Design

Fig. 1 shows the geometry of the proposed compact planar antenna. Two crossed curved dipoles are printed on one side of a 1-mm-thick FR4 substrate, which has a relative permittivity of 4.4 and a loss tangent of 0.02. The lengths of the straight part of two dipoles are L_p. The angles of the curved parts of two dipoles are $\alpha+\Delta\alpha$ and $\alpha-\Delta\alpha$, respectively. The widths of the two dipoles are the same, defined as W_p. The distance between two branches of a dipole is twice of P_o. L_f is the width of the connecting sections, with which a dipole's branch connects the

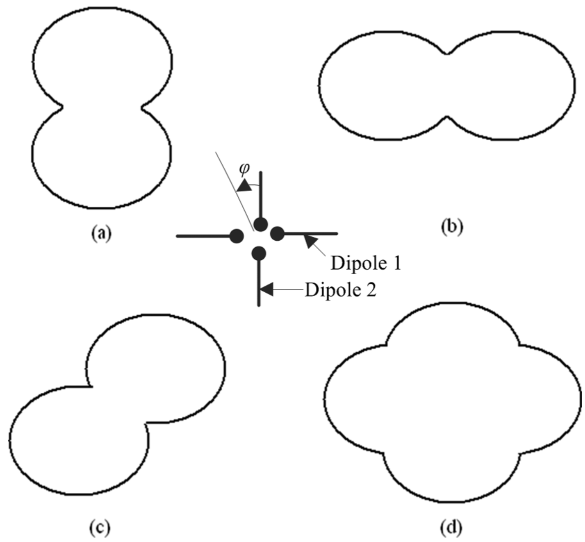

Fig. 2. φ-plane patterns: (a) only the dipole 1 operates; (b) only the dipole 2 operates; (c) dipoles 1 and 2 operate with the same feeding current; (d) dipoles 1 and 2 operate with the feeding current having equal magnitude and 90° relative phase shift.

other dipole's branch. The length and the width of the substrate are $L_{\rm s}$.

Fig. 2 shows the radiation patterns of two crossed dipoles in the φ-plane (crossed dipole plane), which illuminates the principle of the isotropic radiation pattern shaped. As shown in Fig. 2(a), when only dipole 1 operates, the field is maximum in the direction $\varphi = 0°$ at a given moment. In the same way, when only dipole 2 works, the field is maximum in the direction $\varphi = 90°$ at a given instant, as we can see from Fig. 2(b). Thus, when the two crossed dipoles operate with the same feeding current, the field is maximum in the direction $\varphi = -45°$ at a given moment, as shown in Fig. 2(c). Fig. 2(d) shows that the radiation pattern operates with the feeding current having equal magnitude and 90° relative phase shift. By adjusting the lengths of the two crossed dipoles, the surface current of the two radiators could have equal magnitude and 90° relative phase shift. With the radiation pattern omnidirectional in the plane perpendicular to φ-plane, an isotropic radiation pattern could be achieved.

High Frequency Structure Simulator (HFSS) software has been used to simulate the proposed antenna. As we all know, the resonant frequency becomes lower as $L_{\rm p}$ increases, which is also validated by the simulation. Therefore, the desired resonant frequency could be gained by varying the length $L_{\rm p}$. Fig. 3 demonstrates the effect of the angle α on reflection coefficient characteristics of the proposed antenna. From the simulated results, it is observed that the resonant frequency becomes higher as angle α decreases. Hence, the desired central frequency could also be gained by varying the angle α.

Another important parameter is angle $\Delta\alpha$. In Fig. 1, we define the angles of the curved parts of the two dipoles as $\alpha + \Delta\alpha$ and $\alpha - \Delta\alpha$. The difference between the angles of the curved parts of the two crossed dipoles is twice of $\Delta\alpha$. By varying the angle of $\Delta\alpha$, the surface current of the two crossed dipoles is excited with equal magnitude and 90° relative phase shift, so isotropic radiation patterns could be achieved. Fig. 4 exhibits the effect

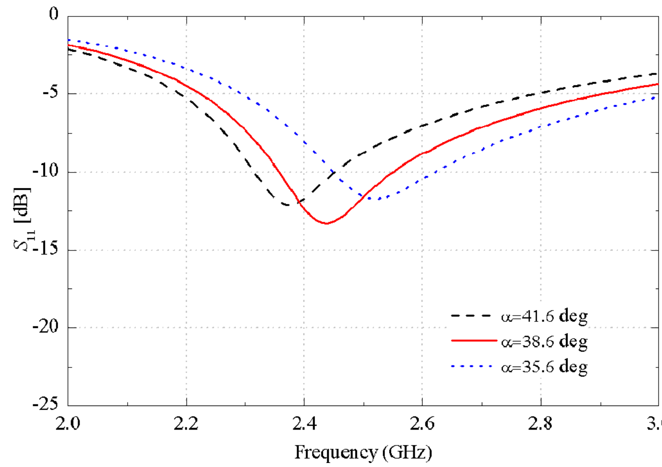

Fig. 3. Simulated reflection coefficient of the antenna for various α.

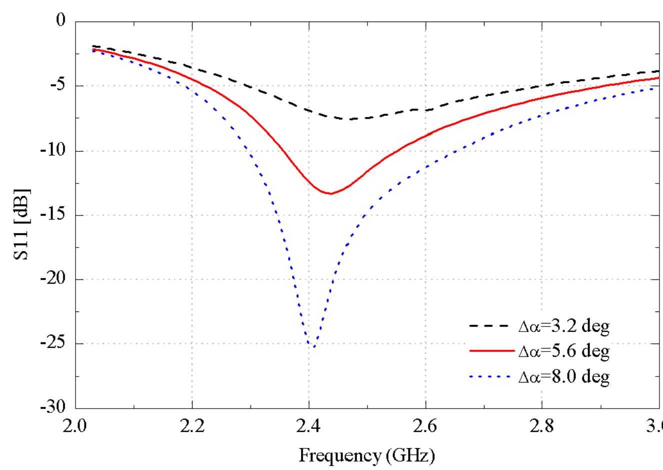

Fig. 4. Simulated reflection coefficient of the antenna for various $\Delta\alpha$.

TABLE I
MAXIMUM AND MINIMUM OF GAINS FOR VARIOUS $\Delta\alpha$

$\Delta\alpha$ (deg)	2.4 （GHz）		2.48 （GHz）	
	Max（dBi)	Min (dBi)	Max (dBi)	Min (dBi)
3.2	0.9775	-7.9812	1.1611	-6.6831
5.6	1.7734	-3.2044	1.7658	-3.2122
8	1.8765	-3.2985	1.8132	-3.6926

of the angle $\Delta\alpha$ on reflection coefficient of the proposed antennas. When $\Delta\alpha$ is 8°, the impedance matching properties are the best. However, the difference between the maximum and the minimum of gains should be taken into account. As listed in Table I, when $\Delta\alpha$ is 5.6°, the differences between the maximum and the minimum of gains are smaller than 5 dB at both 2.4 and 2.48 GHz, and the impedance bandwidth is sufficient at the operating band. Therefore, the difference between the maximum and the minimum of gains could become acceptably small with an optimal $\Delta\alpha$. The distance $P_{\rm o}$ also affects the resonant frequency and the difference between the maximum and the minimum of

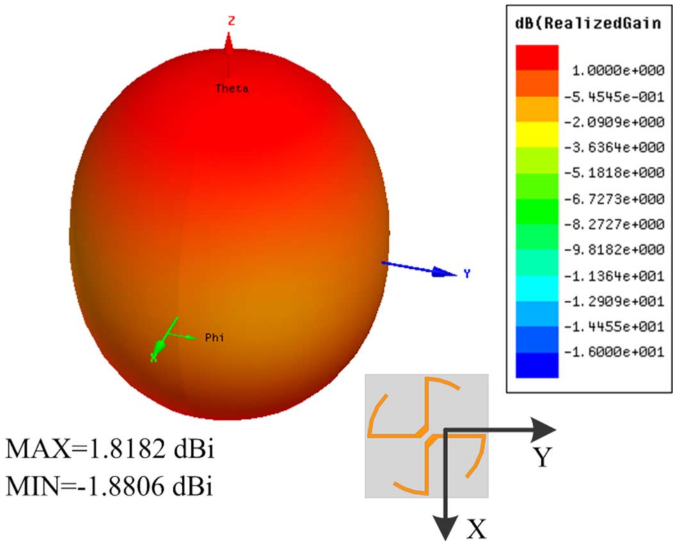

Fig. 5. Three-dimensional simulation radiations pattern of the antenna at 2.44 GHz.

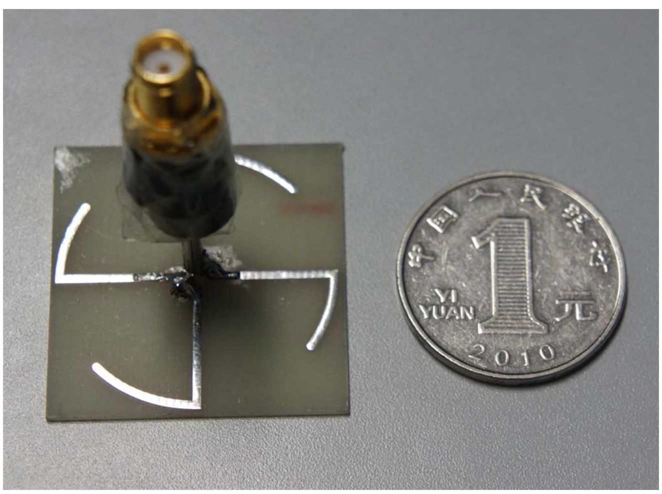

Fig. 6. Photograph of the proposed antenna.

TABLE II
OPTIMIZED VALUES OF THE DESIGN PARAMETERS

L_p	α	$\Delta\alpha$	P_o	L_f	W_p	L_s
13.8 (mm)	38.6 (deg)	5.6 (deg)	1.5 (mm)	1.7 (mm)	0.9 (mm)	32 (mm)

gains. Thus, it should be optimized. The L_f and the W_p are optimized for better matching performance. Finally, the optimized parameters of the proposed antenna are shown in Table II. The simulated three-dimensional radiation pattern of the proposed antenna at 2.44 GHz is presented in Fig. 5. The difference between the maximum and the minimum of gains is 3.6988 dB. It shows that the proposed antenna has the characteristic of an isotropic radiation pattern.

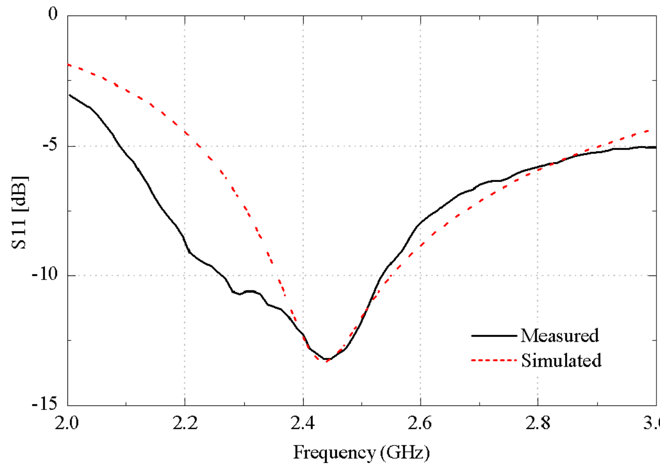

Fig. 7. Simulated and measured results of the reflection coefficient.

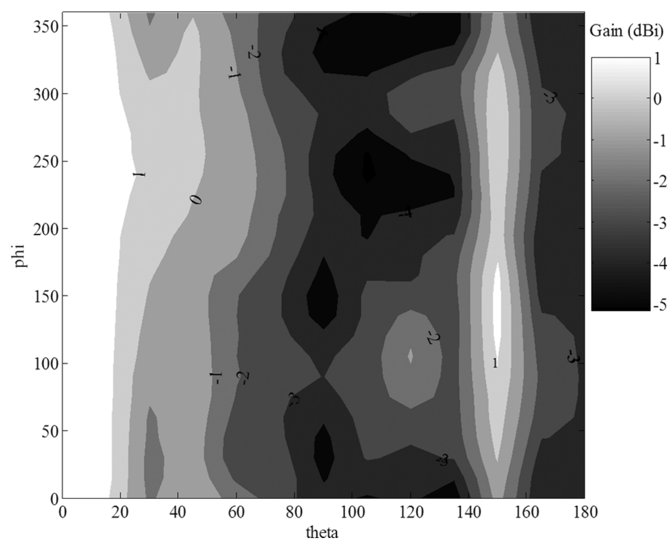

Fig. 8. Gain contour lines at 2.4 GHz.

III. EXPERIMENT RESULTS

To validate the design, a prototype of the proposed antenna is fabricated with the optimized dimensions obtained and shown in Fig. 6. A coaxial cable is used to feed the antenna. The inner conductor is soldered to one conducting section, and the outer conductor is soldered to the other one. Because the current in the feeding coaxial cable will disturb the electromagnetic field of the proposed antenna, some ferrite rings are used to ring the feeding coaxial cable. An Agilent E5071B network analyzer is used in the measurement. Fig. 7 shows the measured reflection coefficient compared to the simulated one. Good agreement is obtained between the simulated and the measured results. The measured impedance bandwidth of $S_{11} < -10$ dB is 270 MHz (2.26–2.53 GHz, 11%), and it covers the wireless local area network (WLAN) band of 2.4–2.48 GHz.

Radiation patterns and gains of the prototype are measured in an anechoic chamber. The gain contour lines in full space of the proposed antenna at 2.4 GHz are shown in Fig. 8. The difference between the maximum and the minimum of gains is 6.67 dB, and it is smaller than 6 dB over 97% of the full space. It illustrates the proposed antenna has the characteristic of an

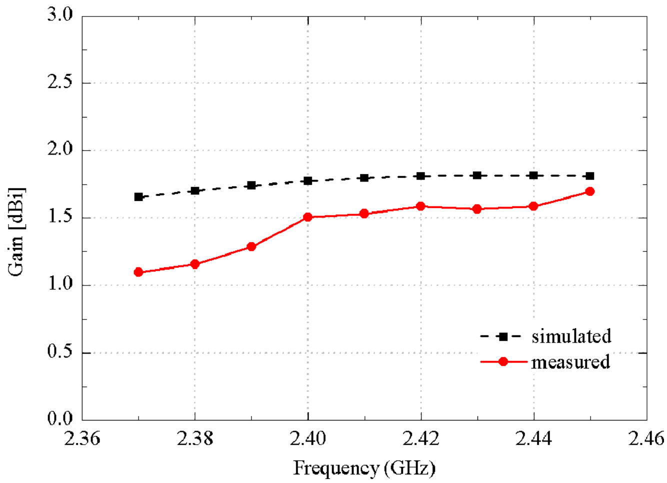

Fig. 9. Simulated and measured gain of the proposed antenna.

TABLE III
MAXIMUM AND MINIMUM OF THE GAIN.

Frequency (GHz)	Max (dBi)	Min (dBi)	Difference (dB)
2.37	1.1	-5.7	6.8
2.40	1.51	-5.16	6.67
2.45	1.59	-5.05	6.64

isotropic radiation pattern. Due to the disturbance of the long feeding cable, the gain contour lines of the antenna are asymmetric when theta is 0° and 180°. Table III lists the differences between the maximum and the minimum of gain at 2.37, 2.4, and 2.45 GHz. There is a frequency shift in measurement, and the simulated difference between the maximum and the minimum of gain is 1 dB smaller than the measured one over 97% of the full space, which is mainly caused by the error introduced by the fabrication and the uncertain relative dielectric constant. Fig. 9 presents the measured peak gains in the band of 2.37–2.45 GHz compared to simulation results. The measured gains fluctuate between 1.1 and 1.69 dBi, which shows approximate agreement with the simulated results. The differences between measurement and simulation mainly are caused by the loss of the substrate and the feeding cable.

IV. CONCLUSION

This letter presents a compact printed isotropic-radiated planar antenna for 2.4-GHz WLAN applications. The structure of the proposed antenna is rather simple and compact, just using two crossed curved dipoles printed on one side of a substrate with the dimensions of $32 \times 32 \times 1$ mm^3. An isotropic radiation pattern is achieved by adjusting the lengths of the two crossed curved dipoles. The measured impedance bandwidth of $S_{11} < -10$ dB is 270 MHz (2.26–2.53 GHz, 11%), and the difference between the maximum and the minimum of gains is smaller than 6 dB over 97% of the full space. The measured gains show approximate agreement with the simulated results. Thus, as a candidate for 2.4-GHz WLAN applications, the proposed antenna is excellent.

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