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Research Article

Wideband Rectangular Foldable and Non-foldable Antenna for Internet of Things Applications

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This article presents a simple wideband rectangular antenna in foldable and non-foldable (printed circuit board (PCB)) structures for Internet of Things (IoT) applications. Both are simple structures with two similar rectangular metal planes which cover multiple frequency bands such as GPS, WCDMA/LTE, and 2.4 GHz industrial, scientific, and medical (ISM) bands. This wideband antenna is suitable to integrate into the short- and long-range wireless applications such as the short-range 2.4 GHz ISM band and standard cellular bands. This lowers the overall size of the product as well as the cost in the applications. In this article, the configuration and operation principle are presented as well as its trade-offs on the design parameters. Simulated and experimental results of foldable and non-foldable (PCB) structures show that the antenna is suited for IoT applications.

1. Introduction

The Internet of Things (IoT) involves data interconnection and exchange between devices and/or sensors [1, 2]. At present, with the explosive development of IoT techniques, increasing applications are found in various fields, including security, tracking, agriculture, smart metering, smart city, and smart home. IoT applications have specific requirements, such as low data rate, low energy consumption, and cost efficiency. Known short-range radio techniques (such as ZigBee and Bluetooth under 2.4 GHz industrial, scientific, and medical (ISM) bands) are not suitable for scenarios of long-distance transmission but with low power consumption [3]. The technical solution based on cellular communications (such as 2G, 3G, and 4G cellular standards) provides larger coverage [4], but it consumes too much power.

There are many size-reduced individual antenna solutions for the 2.4 GHz ISM band [5–7] or cellular standards [8, 9]. Different structures of antenna were proposed to combine these two applications into one broadband antenna [10, 11] which reduces the overall area compared to two individual antennas used. This article proposes a broadband antenna for the short-range 2.4 GHz ISM band and cellular standards to have simultaneous emission and reception. This proposed structure has the simple foldable advantage compared to other broadband antennas [10, 11]. In this article, the foldable and non-foldable antenna design and experimental result are individually presented for different uses in IoT applications. Each individual section shows its design structure and its parameters as well as the simulation of these parameters. Foldable and non-foldable designs were fabricated with experimental results in each section. The bandwidth of both designs is more than 65%, and the operating frequency covers the applications in the global positioning system (GPS), the 2.4 GHz ISM band, and the common 3GPP WCDMA bands as well as the LTE bands. The radiation performance of the non-foldable PCB design is also presented, which shows that this proposed configuration is suitable for simultaneous short-range and long-distance techniques in IoT applications.

2. Antenna Configuration and Operation

A dipole antenna [12] is one of the simple antennas in wireless application, which consists of two identical conductive

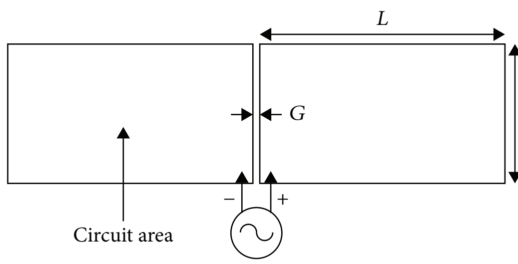

Figure 1: Proposed antenna.

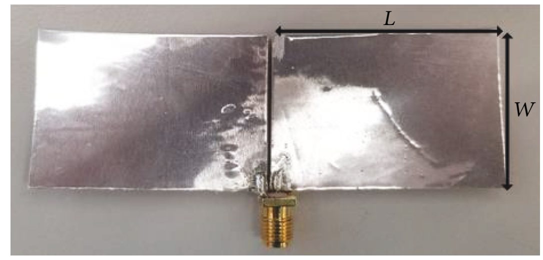

Figure 3: Foldable antenna.

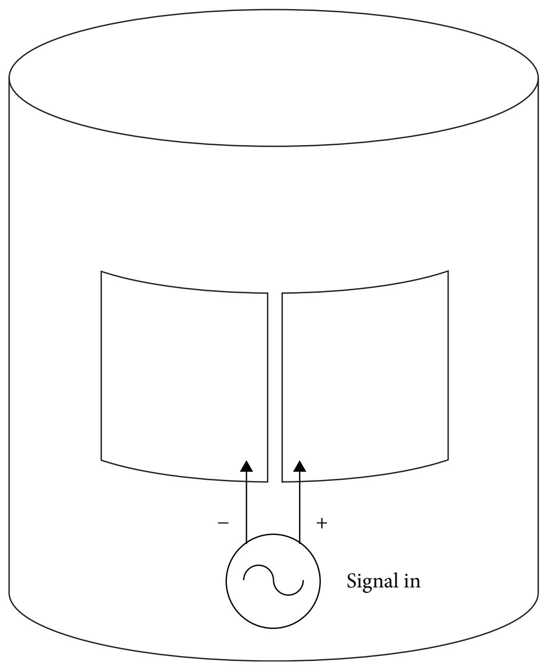

Figure 2: Foldable characteristic in operation.

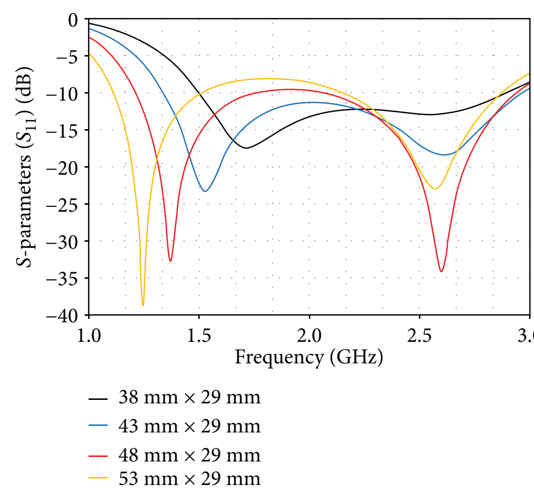

Figure 4: Simulated S-parameters: S_{11} of foldable antenna with different lengths.

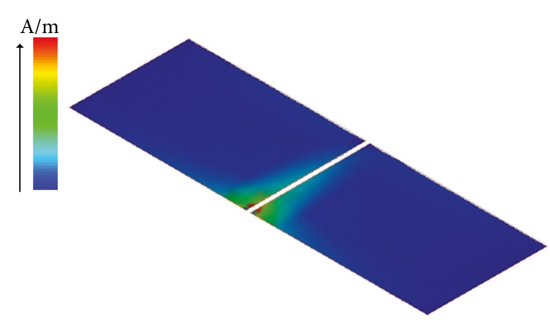

Figure 5: Simulated current distribution (frequency = 1.5 GHz, with $L = 43$ mm and $W = 29$ mm).

elements. Theoretically, its length is required to be a half wavelength (0.5λ) for maximum response [12], and a thicker dipole provides wider bandwidth [13]. The geometry of the proposed planar antenna is shown in Figure 1, which is similar to the dipole antenna. This antenna has a simple structure with two similar rectangular metal planes ($L \times W$) with a gap (G) between the two metal planes for wideband operation. The design parameters are the width (W), length (L), and gap (G) as well as the substrate's height (h) and dielectric constant (ε_r) [13]. The circuit can be placed in the negative metal planes (the left side of the metal plane in Figure 1) which is normally the circuit's ground area. This proposed antenna can be backed by a ground plate for the circuit [13] as well as allow for its foldable characteristic as seen in Figure 2.

3. Foldable Antenna Design and Experimental Result

Figure 3 shows the fabricated foldable antenna which contains two similar rectangular metal sheets ($L \times W$), and the gap (G) between the two metal planes is 1 mm. Figure 4 shows the return losses of this foldable antenna with different lengths of sheets (L) and fixed width ($W = 29$ mm). The results show that this foldable structure has wideband operation and the frequency range is shifted to the lower side with a longer length (L) because the length (L) is closer to the quarter-wavelength of a lower frequency.

Figure 5 shows the simulated current distribution under 1.5 GHz with $L = 43$ mm and $W = 29$ mm, and Figure 6 shows the simulated and measured results of this fabricated foldable antenna in Figure 5. It shows that the simulated and measured results are close to each other with the bandwidth

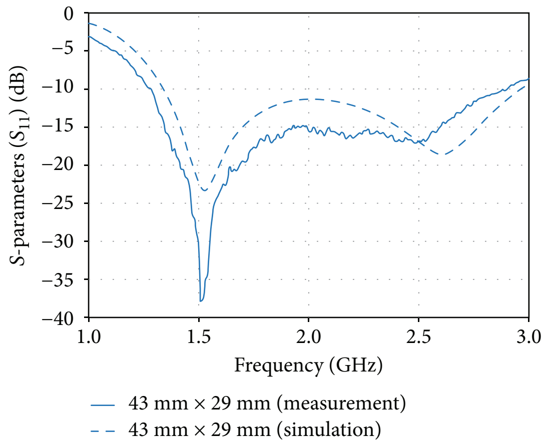

Figure 6: Simulated and measured S-parameters: S_{11} of foldable antenna.

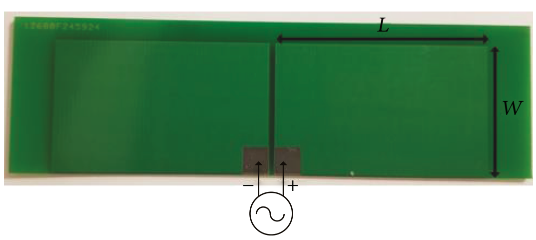

Figure 7: Non-foldable PCB antenna.

of 76% from 1.3 GHz to 2.9 GHz. This range covers the applications in GPS, the 2.4 GHz ISM band, and the common 3GPP WCDMA bands and LTE bands.

4. Non-foldable Antenna Design and Experimental Result

In another prototype, a non-foldable antenna was designed and fabricated on an FR4 printed circuit board (PCB) with a dielectric constant of 4.6 and thickness of 0.8 mm, and the gap (G) between two metal planes is 1 mm. This non-foldable antenna contains two similar rectangular copper planes ($L \times W$) on the FR4 substrate (PCB) shown in Figure 7. The simulated results with different lengths of L and fixed width ($W = 25$ mm) are shown in Figure 8. This non-foldable design also shows that the frequency is shifted to the lower side if length (L) is longer. Figure 9 shows the simulated and measured results with $L = 36$ mm and 41 mm (same width of $W = 29$ mm). The current distribution of this design is similar to those in Figure 5. Simulated and measured results show that they are close to each other with the bandwidth of 76% from 1.35 GHz to 2.75 GHz, which is little worse than the foldable design in Figure 6. The radiation patterns are carried out by an antenna measurement system, and Figure 10 shows the measured radiation patterns of this non-foldable design at frequencies under 1.575 GHz, 1.75 GHz, 1.95 GHz, and 2.45 GHz which are the frequency bands of GPS, WCDMA/LTE,

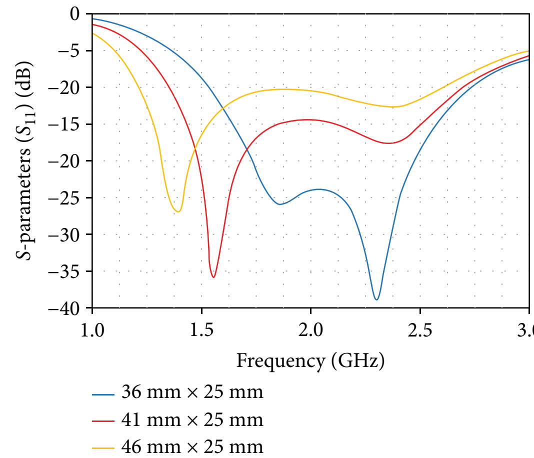

Figure 8: Simulated S-parameters: S_{11} of non-foldable PCB antenna with different lengths.

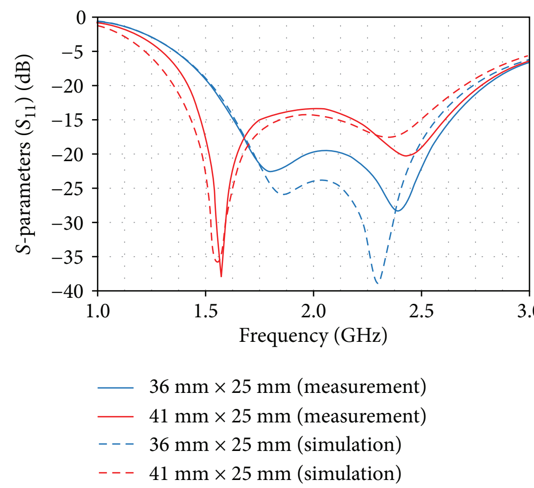

Figure 9: Simulated and measured S-parameters: S_{11} of non-foldable PCB antenna.

and the 2.4 GHz ISM band, respectively, and the gain with different bands is also shown in Figure 11.

5. Conclusions

This paper proposes an antenna with simple foldable and non-foldable structures for IoT applications. To elaborate on the structures, both foldable and non-foldable structures were individually proposed and fabricated for their different uses in IoT applications. Both measurement results of two structures show more than 65% in bandwidth. Their operating frequency covers IoT applications in GPS, the 2.4 GHz ISM band, and the common 3GPP WCDMA and LTE bands. In the non-foldable structure, the gain performances showed that it has good performances compared to the multiple antennas used in individual bands. This wideband, planar, and low-cost (PCB) antenna is one of the suitable and good choices in IoT applications, especially the foldable structure which can be used in wearable applications.

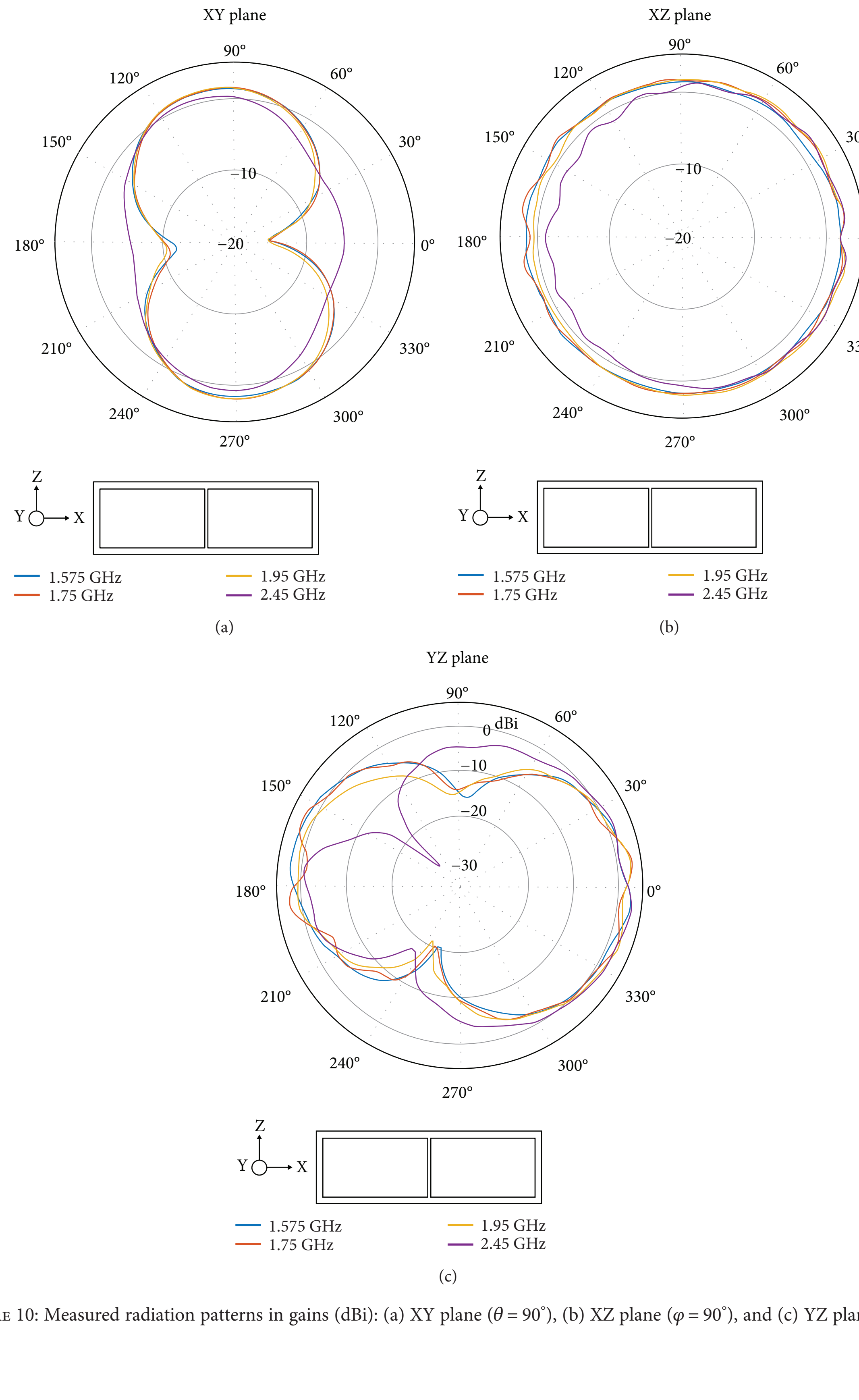

FIGURE 10: Measured radiation patterns in gains (dBi): (a) XY plane ($\theta = 90^\circ$), (b) XZ plane ($\varphi = 90^\circ$), and (c) YZ plane ($\varphi = 0^\circ$).

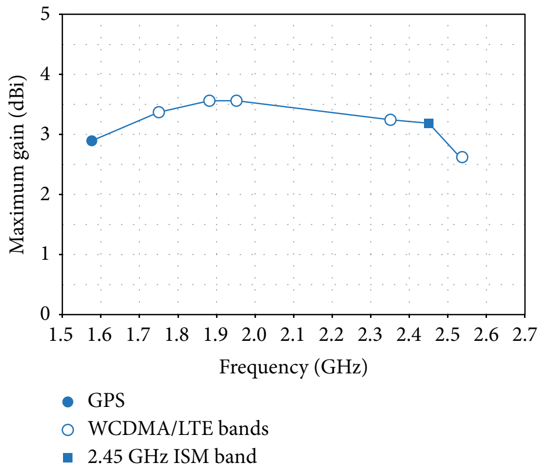

Figure 11: The maximum gain (dBi) of the non-foldable PCB antenna.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Acknowledgments

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