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Research Article

Miniaturized Printed Inverted-F Antenna for Internet of Things: A Design on PCB with a Meandering Line and Shorting Strip

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This paper focuses on a printed inverted-F antenna (PIFA) with meandering line and meandering shorting strip under 2.4 GHz industrial, scientific, and medical (ISM) band for Internet of things (IoT) applications. Bluetooth Low Energy (BLE) technology is one of potential platforms and technologies for IoT applications under ISM band. Printed circuit board (PCB) antenna commonly used in commercial and medical applications because of its small size, low profile, and low cost compared to low temperature cofired ceramic (LTCC) technology. The proposed structure of PIFA is implemented on PCB to gain all these advantages. Replacing conventional PCB line in PIFA by the meandering line and meandering shorting strip improves the efficiency of the PIFA as well as the bandwidth. As a case study, design and measurement results of the proposed PIFA are presented.

1. Introduction

Internet of things (IoT) is a concept that applies current network technology to improve different industries and environment for a higher quality of life in society. IoT is a worldwide network that provides a platform allowing big data transfer and connection between people and things. In a smart city, the wireless connections between sensors and users provide real-time monitoring [1, 2]. Big data is received by sensors, which can be used for solving parking problem [3] and traffic congestion [3] and controlling the quality of air and water [4]. For example, in medical application, data is shared with patients and medical professionals through IoT; therefore, consulting efficiency is enhanced as well as lowering the medical cost [5]. These several applications provide a successful improvement in our society. There are three main layers in the IoT architecture, sensing, network, and application [6]. In the network layer, wireless parts including an antenna and RF front-end circuits are the main challenges for IoT development [7, 8]. There are different wireless solutions, in which Bluetooth Low Energy (BLE) [9] and Zigbee [10] are highly potential suitable platforms for IoT applications. These wireless technologies are operated under 2.4 GHz industrial, scientific, and medical (ISM) band. Nowadays, minimizing the size of the wireless part especially the antenna is still the main challenging research area.

There are many existing size-reduced solutions, and one of the common types is low temperature cofired ceramic (LTCC) antenna [11, 12]. They have different sizes and lengths among these LTCC antennas such as length with 7 mm, 5 mm, and 3 mm. In Figure 1(a), it shows an incident E-field propagates to a vertical dipole of length $L = 0.5\lambda_1$, where λ_1 is the wavelength used. If the current distribution of the dipole is uniform, the actual current distribution is nearly sinusoidal. If the same dipole is used at a longer wavelength, λ_2, so the length is only $L = 0.1\lambda_2$ long. The current tapers almost linearly from the central feed point to zero at the ends in a triangular distribution in Figure 1(b). Assuming dipole with uniform current distribution, the radiation resistance R_{rad} in a free space is given by [13]

$$R_{\text{rad}} = 80\pi^2 \left(\frac{L}{\lambda}\right)^2. \quad (1)$$

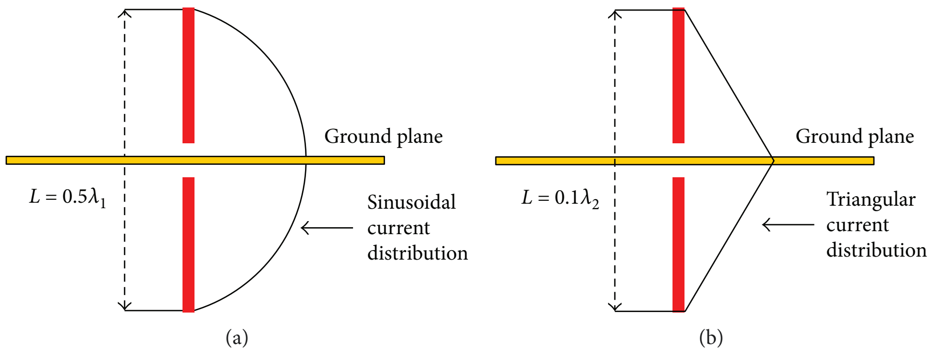

FIGURE 1: (a) Antenna (length = $0.5\lambda_1$) with sinusoidal current distribution. (b) Antenna (length = $0.1\lambda_2$) with triangular current distribution.

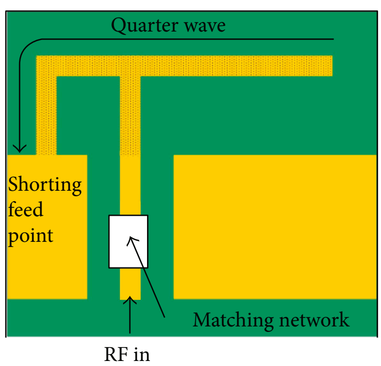

FIGURE 2: Printed inverted-F antenna (PIFA).

TABLE 1: Parameter used in the simulation.

Parameters	Dimension
The width of the strip, w	0.6 mm
The space of each turn, s	0.4 mm
The length of each turn, l	3.5 mm
Distance between shorting feed point and feed point	2.3 mm
Distance to the ground plan	0.8 mm
Area of the antenna ($W \times L_1$)	$15 \times 6\ \text{mm}^2$
Ground plane ($W \times L_2$)	$15 \times 30\ \text{mm}^2$

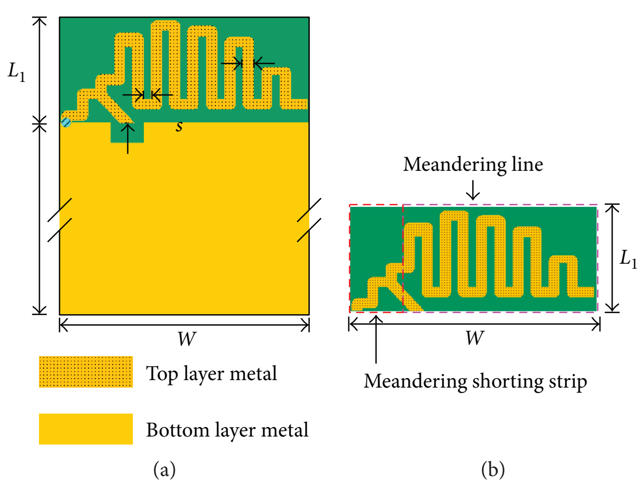

FIGURE 3: (a) Proposed antenna. (b) Antenna with meandering line and meandering shorting strip.

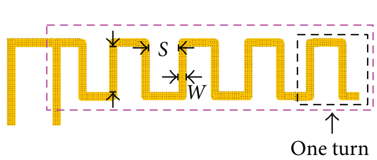

FIGURE 4: Meandering line used in PIFA.

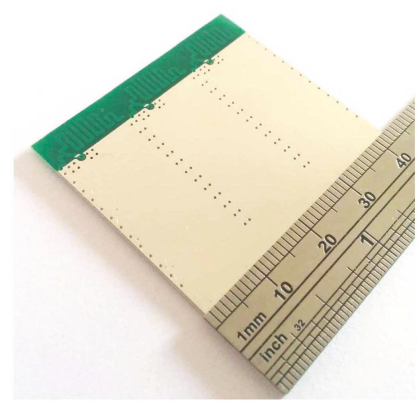

FIGURE 5: Photo of proposed PIFA.

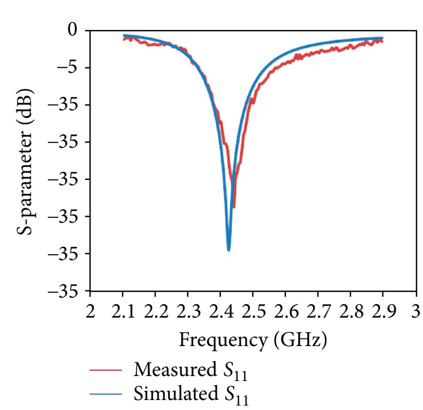

FIGURE 6: Simulated and measured S-parameter, S_{11}.

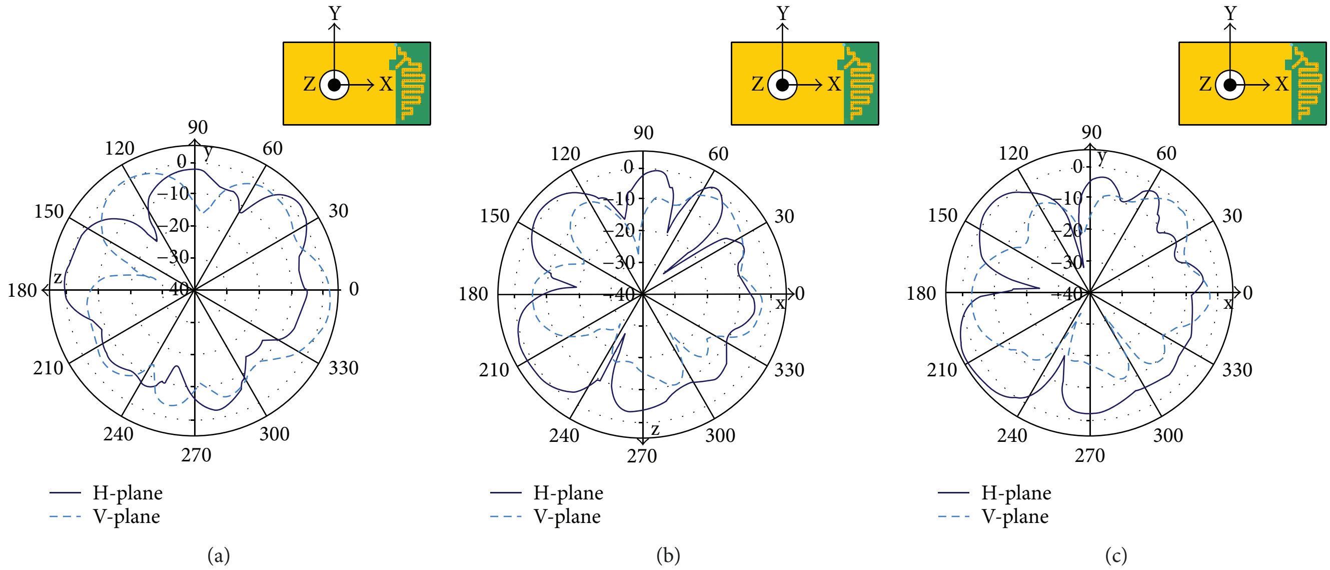

Figure 7: Measured radiation patterns in total fields (horizontal plane (H-Plane) and vertical plane (V-Plane)): (a) Y-Z plane, (b) X-Z plane, and (c) X-Y plane.

For triangular current distribution in Figure 1(b), the radiation resistance is smaller than those in Figure 1(a). Small values of radiation resistance indicate that the performance of the antenna is not very efficient. An antenna with a shorter length but not resonant in the correct frequency leads to poor overall performance since its resonant frequency is higher than the operating frequency, and so a matching network is added to tune to the correct resonant frequency. This matching network is used for maximum power transfer from the radio transceiver to the antenna; however, the antenna still gives poor efficiency as well as resulting extra cost and circuit area.

Several designs [14–16] were proposed to reduce the antenna size by loading with capacitance since this lowers the resonant frequency, making it appear electrically longer. However, the performance of the antenna depends on the quality factor Q of the capacitors used. In general, the components with higher Q have a higher cost. In this paper, a new implementation of the antenna which has the advantages of low profile, small size, and foldable configuration is presented. No matching network is required, and it can be implemented on standard printed circuit board (PCB).

2. Operation of Proposed Printed Inverted-F Antenna (PIFA)

The printed inverted-F antenna (PIFA) is commonly used in the commercial and medical devices compared to other inverted-F antennas (IFAs) [17–20] since it is small, low profile, and low cost. These IFAs [17–20] are in a 3D shape and nonfoldable which occupy a large volume in portable devices. PIFA, therefore, is widely used in small portable devices [21–23]. PIFA is like a monopole printed on the PCB, but it has a shorting feed point along the main resonant structure shown in Figure 2. It has the advantage that the folded part introduces capacitance to the input impedance of the PIFA

Table 2: The gain of the proposed PIFA.

Plane	Peak (dBi)		Average (dBi)	
	Horizontal	Vertical	Horizontal	Vertical
Y-Z	2.31	2.75	−4.12	−3.35
X-Z	1.92	−2.00	−3.25	−7.94
X-Y	4.00	−1.12	−2.51	−7.28

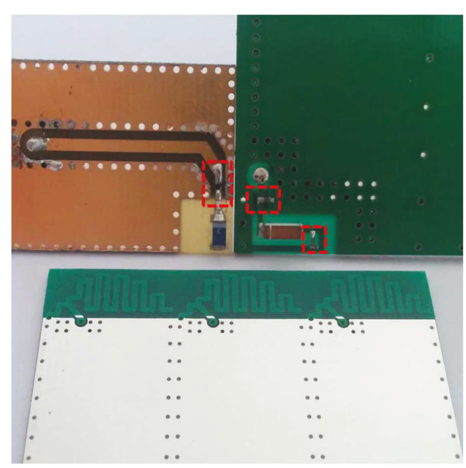

Figure 8: Compared result to Walsin (left) and Murata (right) antennas.

which is cancelled by the shorting feed point. This shorting feed point configuration, therefore, reduces the antenna's size. The matching network may be required for maximum power transfer and, hence, efficient radiation.

Figure 3 shows the proposed antenna which contains two parts, meandering line and meandering shorting strip. Since the ground is classified as part of the antenna during the design, the size $W \times (L_1 + L_2) = 15\,\text{mm} \times (6 + 30)$ mm is

Table 3: Comparison between proposed PIFA, Walsin [12], and Murata antennas [14].

Antenna	Type	Volume (include the matching network)	Extra components
Proposed PIFA	PCB	$15 \times 6.0 \times 0.035\,\text{mm}^3$	No extra cost required
Walsin	LTCC	$12 \times 5.0 \times 1.2\,\text{mm}^3$	1 antenna and 2 passive components
Murata	LTCC	$12 \times 5.0 \times 1.2\,\text{mm}^3$	1 antenna and 2 passive components

chosen (this is the common size of a wireless part). The antenna is simulated and designed on an FR4 PCB with dielectric constant = 4.6, and the PCB thickness used is 0.3 mm. These parameters are used to model the first 2 layers in the multiple-layered PCB structure, and the simulation is obtained by Advanced Design System (ADS).

The resonant frequency of PIFA decreases when the length of the conventional PCB line increases, because of the longer wavelength [13]. This PCB line in the conventional PIFA is replaced by the meandering line in Figure 4. The combination of horizontal and vertical lines forms turns in Figure 4, and the number of turns increases efficiency. The resonant frequency in Figure 4 is much lower than that of the PCB line in the PIFA with equal length [24, 25].

However, one of the disadvantages of the meandering line used is the narrow bandwidth [26, 27] compared to the traditional PIFA in Figure 2. Another disadvantage is a matching network required to be placed at the antenna's input to achieve a good impedance matching for maximum efficiency [28]. The shorting strip of the PIFA becoming a meandering shape increases the bandwidth [29, 30]. Therefore, the meandering shorting strip is then added to increase its bandwidth shown in Figure 3(b). Designing the meandering segment to be a log periodic pattern can improve the antenna's impedance matching [26] shown in Figure 3. Table 1 shows the final dimension used in simulation so that the resonance frequency is close to the operating frequency, 2.45 GHz.

3. Experimental Results

A prototype was designed and fabricated on the FR4 PCB based on the dimension in Table 1, and the photo of the prototype is shown in Figure 5. The return loss is measured by a network analyzer, and the radiation patterns are carried out by an antenna measurement system. In Figure 6, the measured return loss is shown as the red line together with the simulated result as the blue line. The return loss is better than 10 dB within the ISM band. Figure 7 shows the measured radiation patterns in total fields of the proposed PIFA at 2.45 GHz as well as the gain of the antenna in Table 2.

Figure 8 shows the photo of the proposed PIFA compared to the Walsin (monopole) antenna [12] and the Murata antenna [14], which are LTCC antennas. Both need the extra components for good impedance matching. An extra capacitive is added in the Murata antenna [14] to achieve the size reduction, and the large ground plane is required to achieve better efficiency as well. Table 3 shows the comparison table of these 3 antennas. It shows that the Walsin and Murata antennas have a little size smaller than the proposed PIFA. However, the proposed PIFA has only the PCB metal trace's thickness (around 35 μm), which is approximately zero in thickness since it was printed on the PCB; therefore, this can be easily fabricated on the flexible printed circuit (FPC) as well, which is highly foldable for the mechanical housing in portable devices compared to those nonfoldable IFA designs [17–20]. And there is no extra cost required (printed on the PCB) on this proposed PIFA compared to the other two antennas as well as no extra matching network and capacitive load. In Table 4, it shows that the overall gain performance is better than that of the other two antennas.

Table 4: Gain between proposed PIFA, Murata [13], and Walsin monopole antennas [12].

Antenna	Plane	Total average (dBi)
Proposed	Y-Z	−0.708
	X-Z	−1.980
	X-Y	−1.260
Murata	Y-Z	No data in datasheet
	X-Z	−1.761
	X-Y	−3.318
Walsin	Y-Z	0.891
	X-Z	−1.846
	X-Y	−2.556

4. Conclusion

This paper proposes a minimized PIFA design suitable for IoT and other ISM band applications. To elaborate on this, the architecture of the PIFA on PCB with meandering line and meandering shorting strip was proposed. The measurement result of return loss and gain performances has shown that it has better performances compared to the LTCC antennas and there are no extra components required for good impedance matching. This proposed PIFA is a paradigm of choice compared to others keeping the portability of devices with low cost and good performance.

Conflicts of Interest

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

Acknowledgments

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