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Design of Compact Wideband Meandering Loop Antenna with a Monopole Feed for Wireless Applications

Yibo Wang, Lijia Zhu, Hongwei Wang, and Guangli Yang*

Abstract—A novel compact wideband printed loop antenna is presented for wireless applications. The wideband characteristic is achieved by combining three different loop resonant modes of the antenna. The antenna geometry is simple and consists of a rectangular meandering loop, a coplanar waveguide (CPW) structure, and a monopole feed. This proposed antenna has the dimension of only $27\times20\times1\,\mathrm{mm}^3$ while operates at a wideband from 2.4 GHz to 5.9 GHz (84.3%) with stable gain, radiation pattern and vertical linear polarization. This antenna is suitable for WLAN and future 5G sub-6 GHz spectrum communications. Good agreement between the simulation and measurement is obtained.

1. INTRODUCTION

The next generation mobile communication systems (5G) require higher wireless transmission throughput and larger data capacity. Subsequently more spectrum resources will be used, especially sub-6 GHz. The low frequency below 6 GHz is the 5G core band for seamless and wide area coverage due to its feature of good channel propagation [1, 2]. There exists a great demand in designing compact size, low cost and easy fabrication antennas with wide bandwidth to cover more spectrums for 5G applications.

Many types of wideband planar antennas have been proposed in the literature, including Y-shaped, ear-shaped, fork-shaped monopole antennas with meandering strips [3–5], CPW-fed slot-loop antennas [6–8], proximity-coupled microstrip antennas [9, 10] and metamaterial-loaded printed antennas [11, 12]. However, there are still many deficiencies in the antennas mentioned above. For example, only part of the band of 2.4–5.9 GHz is covered by the antennas in [3, 6, 11], which therefore are not suitable for broadband applications. The asymmetric structure of antennas in [4, 12, 13] may result in distortion of the radiation pattern and increase of the cross-polarization level [14, 15]. The large size or complicated structure of antennas in [9, 10, 16] may create integration difficulty in 5G communication systems and add high manufacturing costs.

In this paper, a meandering loop structure [17, 18] is introduced with multi-mode resonant properties to cover wide bandwidth and realize antenna size miniaturization. The proposed antenna in this work has a simple structure with a small size of $20\times27\,\mathrm{mm}^2$. It can generate three resonances, namely, 0.5-λ, 1-λ, 1.5-λ loop modes, corresponding to frequencies at 2.5, 4.6 and 5.8 GHz. By adjusting the dimensions of the antenna properly, all the modes can cover the WLAN and future 5G candidate bands such as 3.4–3.6 GHz, 3.6–4.2 GHz, and 4.4–4.9 GHz. Furthermore, the antenna has omnidirectional radiation patterns and stable gains in the working bands. Detailed operating principles of the proposed antenna are described, and a prototype antenna is also fabricated and experimentally investigated in this paper.

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* Corresponding author: Guangli Yang (guangli.yang@shu.edu.cn).
The authors are with the Shanghai Institute for Advanced Communication and Data Science, Key Lab of Specialty Fiber Optics and Optical Access Network, Shanghai University, Shanghai 200072, P. R. China.

2. ANTENNA STRUCTURE AND DESIGN PRINCIPLES

In order to explain the working principle of the proposed antenna, the design process is presented in Figure 1, and the simulated results are presented in Figure 2. All the antennas are designed on a 1 mm thickness FR4 substrate, which has a relative permittivity of 4.4 and loss tangent of 0.02. The overall dimension of the proposed antenna is only $27 \times 20\,\text{mm}^2$. The CPW feed line width S of 3.5 mm and the gap distance G of 0.3 mm are designed to obtain the 50-Ω characteristic input impedance. Antenna 1 is a monopole antenna with a CPW feeding structure. This design can excite one monopole resonant mode around 5.3 GHz. The three loop modes can be excited when a rectangular-loop structure is introduced by enclosing the ground as shown in Antenna 2, and the monopole is as an antenna exciter. Finally, the loop path is modified by adding two meandering strips to combine the resonant modes, which enables the antenna to cover the operating bands from 2.4 to 5.9 GHz.

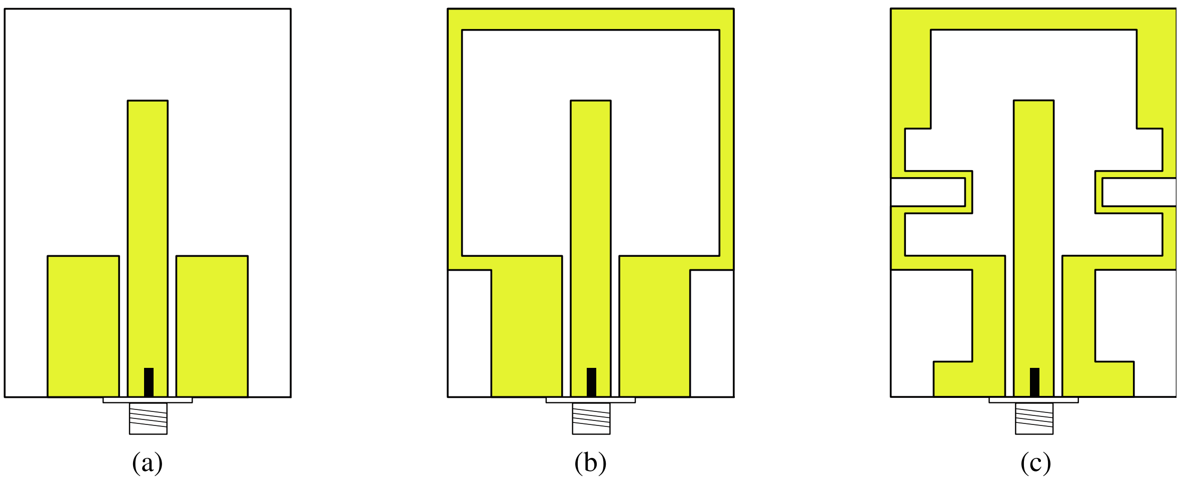

Figure 1. Design process of the proposed antenna, (a) Antenna 1, (b) Antenna 2, (c) Antenna 3.

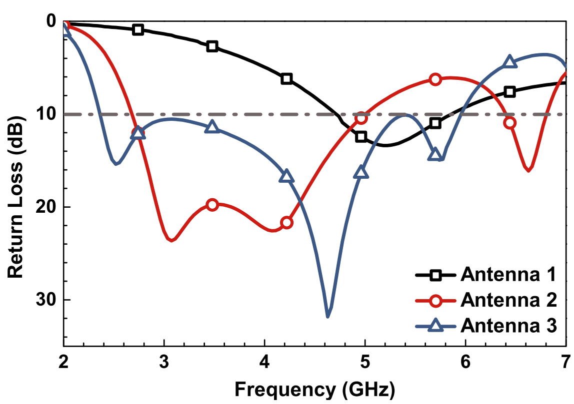

Figure 2. Simulated return loss of various antennas involved.

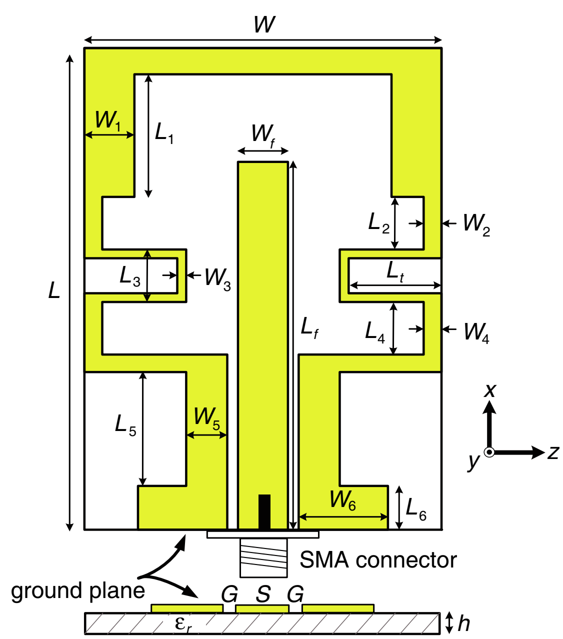

Figure 3. Geometry of proposed antenna.

Figure 3 shows the detailed configuration of antenna 3 (i.e., the proposed antenna), and the optimized parameters are demonstrated in Table 1. By applying a meandering loop radiator and a monopole radiator, it is found that the antenna has three loop resonant modes and one monopole mode, namely, 0.5-λ loop mode for the lower band, 1-λ loop mode for the middle band, and 1.5-λ loop mode for high band. Clearer explanations can be seen from the current distributions in later part of this paper.

Table 1. Geometrical parameters of the proposed antenna.

Parameters	Values (mm)	Parameters	Values (mm)	Parameters	Values (mm)
W	20	W_3	0.5	W_6	5
L	27	L_3	3	L_6	2.5
W_1	2.8	W_4	1	W_f	2.8
L_1	7	L_4	3	L_f	21
W_2	1.3	W_5	2.3	L_t	5.5
L_2	3	L_5	6.5	h	1

3. EXPERIMENTAL RESULTS AND ANALYSIS

An antenna prototype is fabricated and measured based on the detailed values of the proposed model. The return loss measured by Agilent N5227 vector network analyzer agrees well with the simulation as shown in Figure 4. It can be observed that the 10-dB impedance bandwidth is 84.3% (2.4–5.9 GHz), which can cover WLAN and new sub-6 GHz bands in 5G applications.

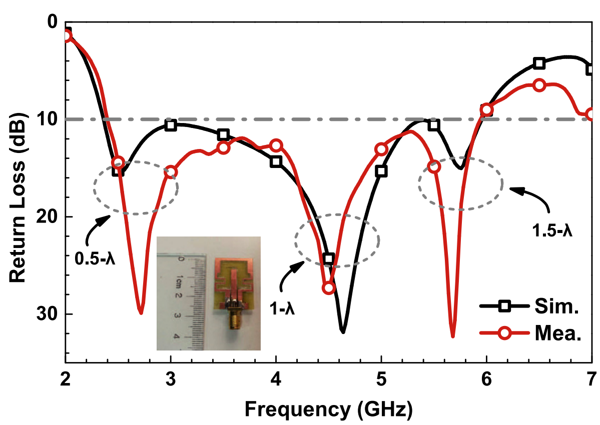

Figure 4. Measured and simulated results for proposed antenna.

In order to further comprehend how the loop path can affect the resonant modes, the influence of the length of the meandering strips L_t on return loss is shown in Figure 5(a). As shown in the plot, the higher band shifts left when the length L_t increases (from 5.2 mm to 5.8 mm), while the middle and lower resonant modes are not affected at all. Figure 5(b) shows that the impedance matching of the working bands is mainly affected by W_3. A decrease (from 0.9 mm to 0.5 mm) in the width W_3 will extend the bandwidth and improve the impedance matching. By fine-tuning the geometry crucial parameters independently using the numerical simulations, a wideband antenna is achieved.

To indicate the antenna working modes, the vector surface current distributions at the resonant frequencies of 2.5, 4.6 and 5.8 GHz are simulated and plotted in Figure 6. As can be seen clearly in Figure 6(a), the current paths at 2.5 GHz are approximately half-wavelength (0.5-λ) of the loop including one surface current of null. As shown in Figure 6(b), the current distribution is approximately

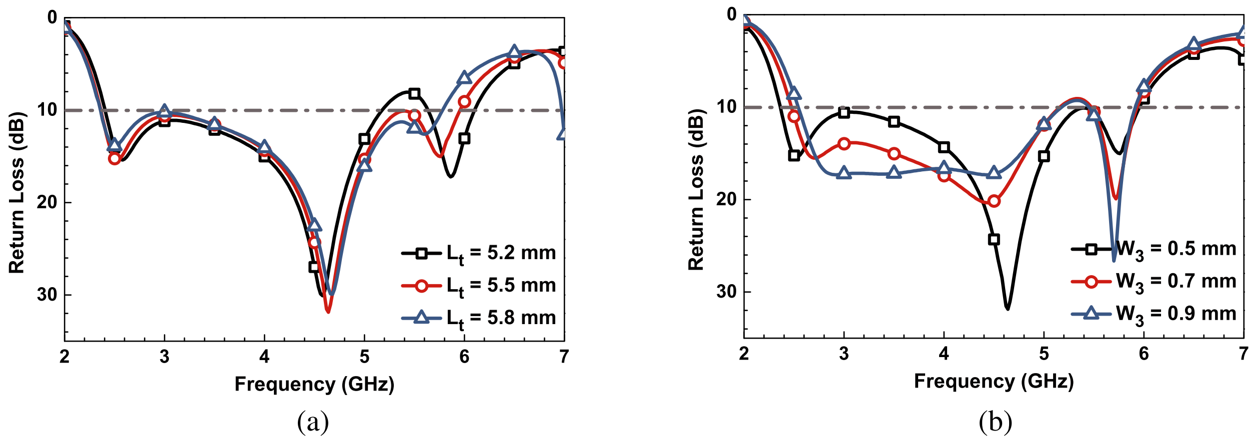

Figure 5. Simulated return loss of the proposed antenna by tuning parameters, (a) parameters L_t, (b) parameters W_3.

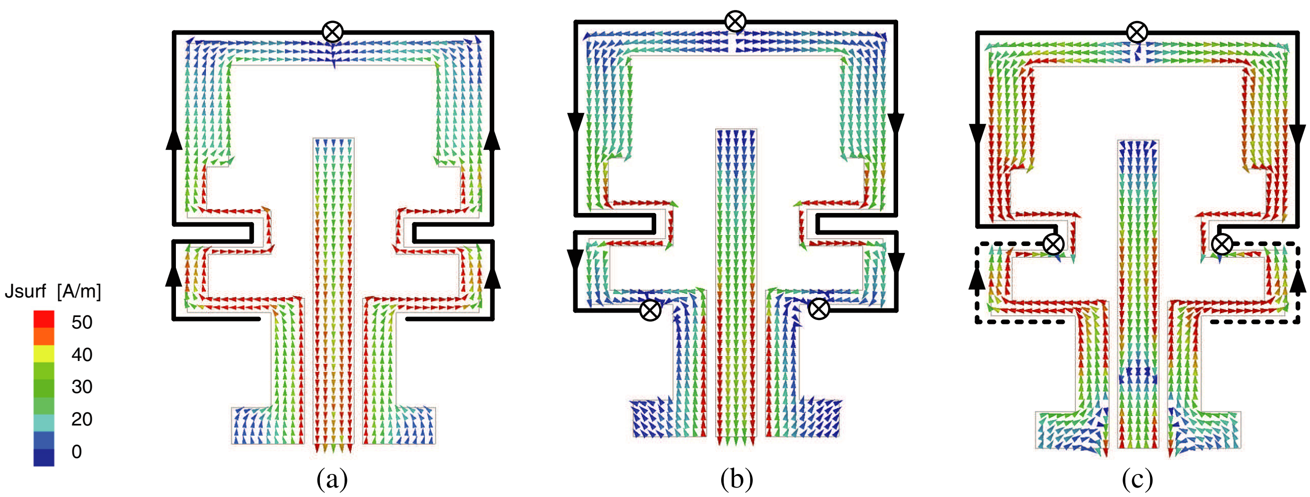

Figure 6. Surface current distributions of proposed antenna, (a) 2.5 GHz, (b) 4.6 GHz, (c) 5.8 GHz.

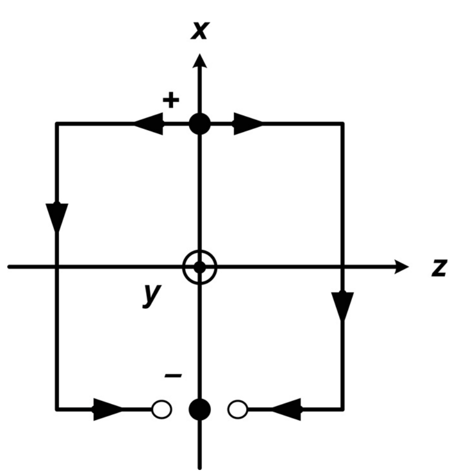

Figure 7. Current flowing under even-mode.

one wavelength (1-λ) long including two maximum currents and three surfaces of null. The monopole radiator not only excites the loop modes but also contributes to the middle band resonance according to the current distribution. As depicted in Figure 6(c), two maximum currents and three surfaces of null can be observed along the loop paths indicating that it is about one-half-wavelength (1.5-λ) at 5.8 GHz. From the current distribution paths shown above, it can be observed that the operating mode of the loop antenna is even-mode [19] as shown in Figure 7. When the meandering strips are added to the loop structure, it can generate different even-modes that resonate respectively at 0.5-λ, 1-λ, and 1.5-λ modes. The current density on the vertical edges is large, and the direction is same as the current vector. On

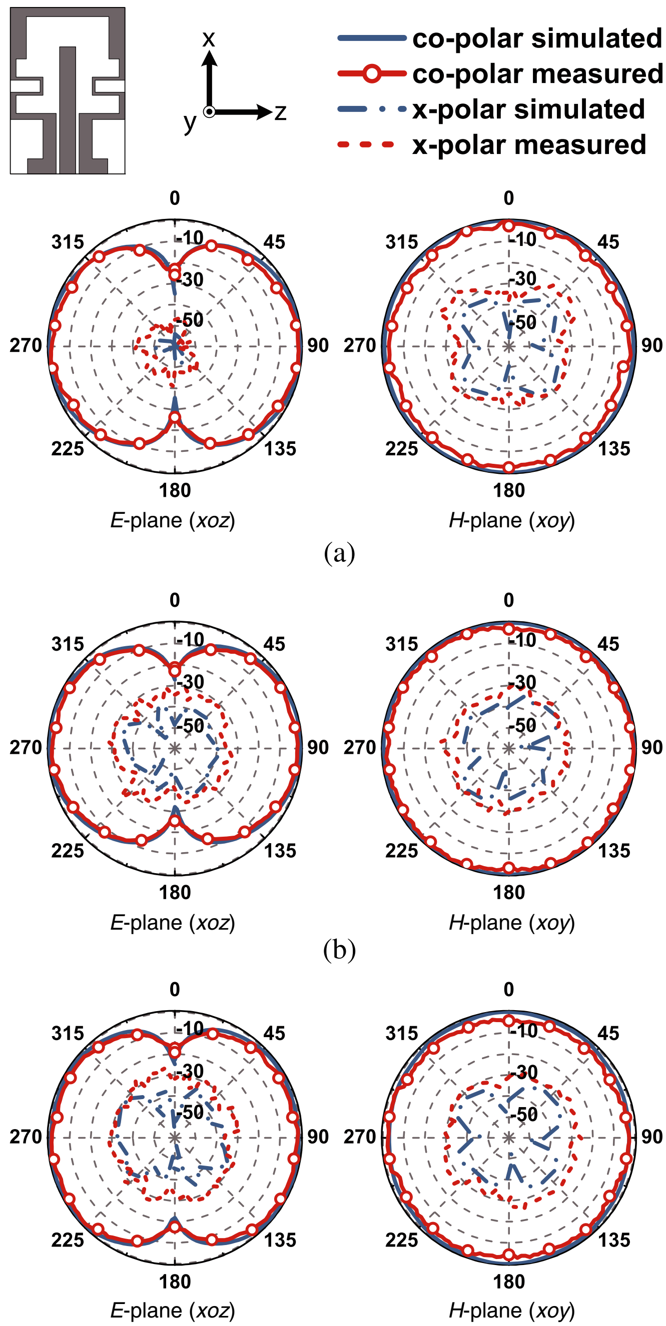

Figure 8. Measured 2-D radiation patterns of the proposed antenna, (a) 2.5 GHz, (b) 4.6 GHz, (c) 5.8 GHz.

the contrary, the current density on the horizontal edges of the loop is relatively small. Therefore, the radiation fields of the antenna are vertically polarized. The performance of bandwidth and radiation properties of the conventional electrical small antenna are affected by the shape and size of the ground plane. Radiator and ground plane are both distributed with electric current that causes unbalanced radiation and impedance matching difficulties. Since the ground plane current of the proposed antenna is small, the ground size can be reduced to decrease the radiation interference from the ground [20, 21].

Figure 8 shows the measured radiation patterns of the proposed antenna at 2.5, 4.6 and 5.8 GHz in two principal planes (*xoy* and *xoz* planes), respectively. The antenna has almost bidirectional patterns in the *E*-plane (*xoz*-plane) and nearly omnidirectional in the *H*-plane (*xoy*-plane). Compared with co-polarization (vertical polarization) radiation patterns, cross-polarization (horizontal polarization) radiation patterns of the proposed antenna are relatively weak. The measured antenna peak gains are 2.35, 3.26 and 3.46 dBi for the 2.5, 4.6, and 5.8 GHz bands, respectively. The corresponding efficiencies are 57.6%, 74.3% and 79.6%. Figure 9 illustrates the measured maximum gains and radiation efficiencies at the working bands. These radiation characteristics indicate that the proposed antenna is suitable for the 5G/WLAN wireless applications.

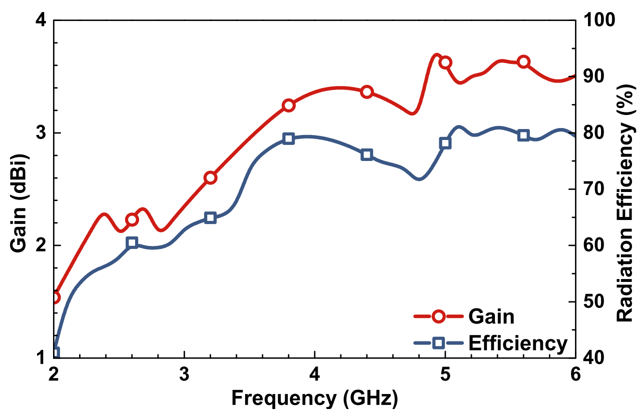

Figure 9. Measured gain and efficiency of the proposed antenna.

Table 2 shows the comparisons of the proposed antenna with those reported in references in terms of dimension, 10-dB impedance bandwidth and gain. The proposed antenna has exhibited the advantages of simple structure and small volume of $27 \times 20 \times 1\,\text{mm}^3$ with bandwidth coverage for WLAN and new sub-6 GHz bands for 5G applications.

Table 2. Comparisons between proposed antenna and reference antennas.

Ref.	Dimension (mm^3)	10-dB impedance bandwidth	Gain (dBi)
1	$36.5 \times 23 \times 0.8$	35.4%	2.5–2.8
2	$37 \times 18 \times 1$	45.3%	2.1–3.5
3	$34 \times 18 \times 1.6$	26.5%	−0.1 to 4.7
5	$45 \times 57.4 \times 1$	102.9%	4.1–5.8
7	$27 \times 24 \times 0.8$	21.7%	1.8–4.2
8	$27 \times 24 \times 1.6$	19.3%	1.1–3.2
9	$30 \times 21 \times 1.6$	46.1%	3.7–4
10	$45 \times 40 \times 1$	36.2%	2.3–3.2
Proposed	$27 \times 20 \times 1$	84.3%	2.0–3.6

4. CONCLUSION

A novel wideband printed loop antenna is well designed and fabricated. By introducing a meandering loop structure, the proposed antenna can combine different resonant modes to obtain a wide operating bandwidth of 84.3% from 2.4 to 5.9 GHz. An antenna prototype is fabricated and measured, and good agreement between measurement and simulation results is obtained. The excellent performance indicates that the proposed antenna can be a potential candidate for 5G/WLAN applications.

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