Wideband dipole antenna with inter-digital capacitor*

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A dipole antenna with wideband characteristics is presented. The proposed antenna consists of a dipole with periodic capacitive loading and a pair of coplanar striplines (CPSs) as an impedance transformer. By adding interlaced coupling lines at each section, periodic capacitive loading is realized. The periodic interlaced coupling lines divide each arm of the dipole into five sections, and currents are distributed on different sections at different frequencies, which is useful to achieve a wide impedance bandwidth. By parametric study using HFSS, the optimized parameters of this dipole antenna are obtained. In order to validate the simulation results, a prototype of the proposed dipole antenna is fabricated and tested. The results show that the proposed antenna can achieve a gain of 3.1 dB–5.1 dB and bandwidth of 51% for $|S_{11}| < -10$ dB over the band of 3.9 GHz–6.6 GHz, indicating its good radiation performance and radiation efficiency.

Keywords: dipole antenna, wideband antenna, inter-digital capacitor

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1. Introduction

Printed dipole antennas are widely used in many areas such as wireless communication and radar systems. They enjoy their advantages of light weight, low cost, easy fabrication, and suitability for integration with microwave integrated circuit modules.[1,2] A narrow bandwidth is, however, the common drawback of the printed dipoles, which is often insufficient for many applications.[3,4] Generally speaking, a regular dipole antenna has an impedance bandwidth of about 10% with reflection coefficient ($|S_{11}|$) less than -10 dB. Therefore many attempts have been made for increasing the bandwidth of the printed dipole antennas.[5–8]

One of the methods used in the literature for bandwidth enhancement is to fold an antenna structure.[9] However, this antenna provides only about 1-GHz bandwidth and the gain is only about 2 dB. In addition, the folded structure leads to a potential increase in conductor loss due to the physical length of the antenna structure.

Another method used for increasing the bandwidth of dipole antenna is to use an additional shorter dipole as matching element.[10] This twin-dipole is able to achieve a bandwidth of 131% ($|S_{11}| < -10$ dB) from 1.6 GHz to 7.1 GHz. However, the radiation gain patterns are not omnidirectional at high frequencies, which is undesirable for some applications.

Recently left-handed (LH) dipole antennas have been investigated both numerically[11,12] and analytically.[13,14] In those studies, it was demonstrated that the relationship between electrical strength and frequency for conventional antenna is opposite to that for LH-loaded antenna, thereby leading to the fact that the wavelength reduces with frequency decreasing in the LH-loaded antenna. Moreover, the input impedance and resonant frequency of LH antenna depend on the elements of the unit cells instead of the total length. However, main drawbacks of this method are low gain and narrow bandwidth.

In this paper, a wideband dipole antenna is realized by adding interlaced coupling lines at each section, similar to a mu-zero resonance (MZR) antenna.[15,16] The innovation point of this paper is to introduce the periodic capacitive loaded dipole antenna, which allows current along the dipole to be kept in phase and achieve a wide impedance bandwidth. The proposed antenna can provide a wide impedance bandwidth of 2.7 GHz (from 3.9 GHz to 6.6 GHz, 51%) and an average gain of 3.98 dB. The radiation patterns are stable across the entire bandwidth with low cross-polarization and it has an average radiation efficiency of 70%. To the best knowledge of the authors, there has been no work on discussing the interlaced coupling dipole antenna.

2. Antenna description

The basic geometry of a dipole antenna with interlaced coupling lines is shown in Fig. 1. It comprises a dipole with interlaced coupling lines and a pair of coplanar striplines (CPSs) as an impedance transformer. A periodic inter-digital capacitor is realized by adding slots in each dipole cell. The engraved slots are symmetrically structured with respect to the center of the parallel feedline, and each slot has the following parameters: gap between the two bulgy stubs w, inner bulgy stub

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length L_k, and length L_f of the feedline. The antenna is designed and simulated using the Ansoft HFSS full-wave simulator. The finally optimized parameters of this antenna are as follows: $w = 0.1$, $L_k = 1.4$, $L_f = 4.5$ (all in mm). The others are shown in Fig. 1. The length of the proposed antenna is fixed to be 60 mm with the central frequency $f_c \approx 5$ GHz. The width of the dipole is 2.3 mm. The proposed antenna is printed on an FR4 substrate of thickness 0.8 mm and $\varepsilon_r = 4.4$. The antenna lies in the xy plane with its normal direction being parallel to the z axis.

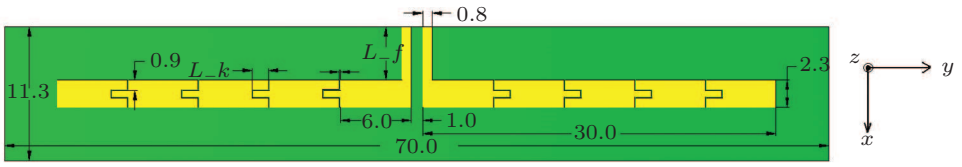


Fig. 1. (color online) Antenna structure of the proposed wideband dipole.

3. Parametric study and discussion

In order to fully understand the influence of these parameters on the impedance bandwidth and gain, a parametric study is carried out by varying each parameter, with the remaining parameter values kept at their optimum values. Figures 2(a)–2(c) show the results of simulated parametric studies on the reflection coefficient S_{11} and gain profile, when the spacing w between the two bulgy stubs, inner bulgy stub length L_k, and length L_f of the feedline are varied.

Figure 2(a) shows that by increasing width w, the resonant frequencies increase from 4 GHz to 4.7 GHz, while the gains gradually decrease and the impedance bandwidths ($|S_{11}| < -10$ dB) reduce. Figure 2(b) depicts responses of reflection coefficients and gains for different values of L_k. When L_k is increased, the resonant frequencies decrease but the impedance bandwidths ($|S_{11}| < -10$ dB) increase. The gain curves are similar to those in Fig. 2(a). The third parameter studied is the length of feedline L_f. As depicted in Fig. 3(c), the antenna impedance bandwidth is very sensitive to the variation of L_f, however, it has little effect on the antenna gain in the middle frequency band. So for this proposed prototype, $w = 0.1$ mm, $L_k = 1.4$ mm, $L_f = 4.5$ mm are chosen to achieve good impedance matching and gain over a wide frequency band, but note that the w, L_k, and L_f are not the only parameters to tune the value of the impedance bandwidth. The other parameters such as the widths of the feed and the dipole can also be used to tune the impedance, but will not be displayed here for brevity.

To better understand the wideband property of this proposed dipole antenna, we simulate the surface current distributions at 4, 5, and 6 GHz. A conventional dipole antenna of the same size is used as a reference for comparison. The current distributions of both the dipole antennas are shown in Fig. 3. The CPS surface current distributions are not shown in Fig. 3 for clarity.

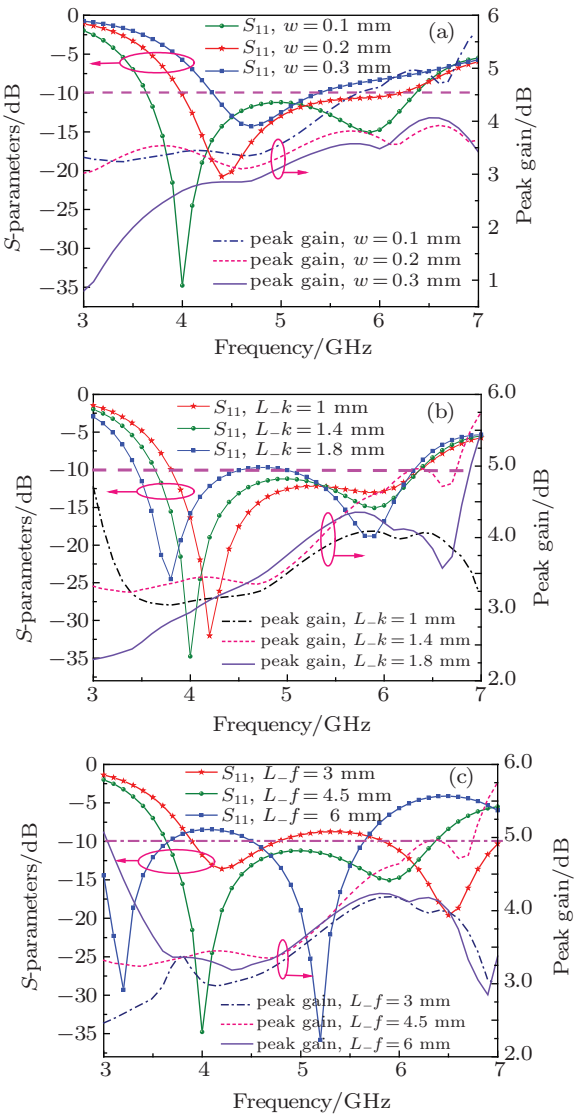


Fig. 2. (color online) Parametric studies by varying the (a) spacing w, (b) bulgy stub length L_k, and (c) feedline length L_f.

As revealed in Figs. 3(a) and 3(b), the current in the proposed antenna is in phase with the dipole and mainly distributes near the top of the CPS at middle and low frequencies. However, at high frequency 6 GHz, surface current concentrates at the ends of the three sections as shown in Fig. 3(c). Different from the scenarios in Figs. 3(a) and 3(b), the current at the end of the CPS is 180° out of phase with the dipole, which means that at this frequency point, the proposed dipole antenna has a low radiation efficiency. For conventional dipole antenna, the current distribution at 4 GHz is shown in Fig. 3(d). For the cases of 5 GHz and 6 GHz, the current distributions are almost the same and they are not displayed here for brevity. So the bandwidth of the conventional dipole antenna is very narrow.

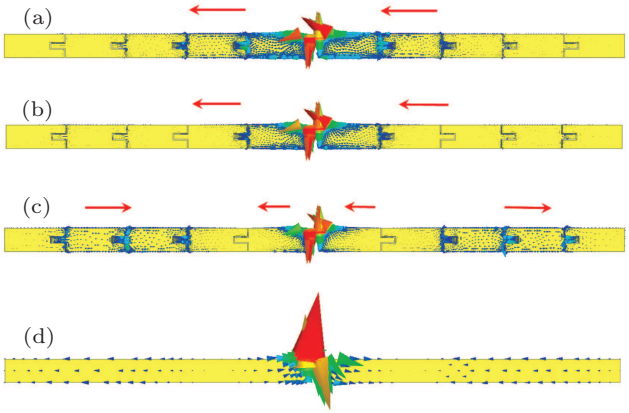


Fig. 3. (color online) Simulated surface current distributions of the proposed dipole antenna at (a) 4 GHz, (b) 5 GHz, (c) 6 GHz, and (d) conventional dipole antenna at 4 GHz.

From the above studies, it can be seen how the structural parameters and the surface current distributions affect the bandwidth and the mechanism of this wideband dipole antenna. We can draw the following conclusions.

1) Each discussed parameter has an important influence on bandwidth;

2) The wideband property of this proposed dipole antenna is generated by the current distribution.

In other words, each section of the dipole corresponds to its frequency range different from that which the other section corresponds to.

4. Experimental results

According to the parameters given in Section 2, a prototype of the proposed antenna is built (as shown in the inset of Fig. 4) and tested. In Fig. 4, the measured and simulated S_{11} of the proposed antenna are presented. For comparison, the simulated S_{11} of the conventional dipole antenna with the same geometry is also shown in Fig. 4. As seen from the reflection coefficient curves, the impedance bandwidth of the proposed dipole antenna is significantly improved. Its impedance bandwidth is 51% for $|S_{11}| < -10$ dB over the band of 3.9 GHz–6.6 GHz. The simulated resonant frequency of the proposed antenna is 4 GHz, whereas the measured resonant frequency is 4.3 GHz. The difference between simulation and measurement may come from test error and fabrication error.

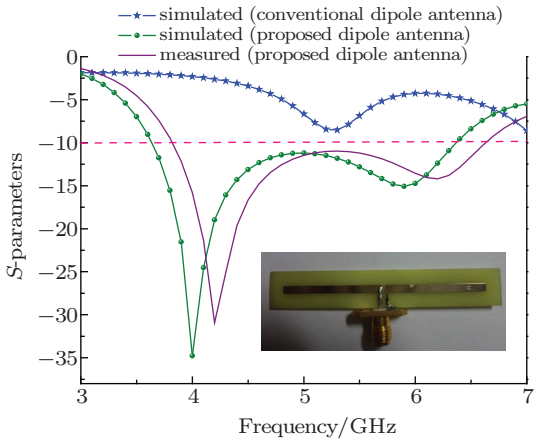


Fig. 4. (color online) Measured and simulated values of S_{11} of the proposed antenna.

The simulated and measured radiation patterns in the three principal planes are compared with each other at 4 GHz, 5 GHz, and 6 GHz as shown in Fig. 5(a)–5(c), respectively, where good agreement between the simulations and measurements can be observed. As seen from all the radiation patterns in the *xz* plane, it is clear that good omnidirectional radiation is obtained. In addition, it is found that the radiation patterns in other planes (*xy* plane and *yz* plane) are very similar to the ideal "8-shape" dipole patterns.

Figure 6 illustrates the measured gain and efficiency against frequency of the proposed antenna. It clearly shows that the measured antenna gain varies between 3.1 dB and 5.1 dB from 3.9 GHz to 6.6 GHz with an average gain of 3.98 dB. The efficiency of the proposed dipole antenna varies from 84% to 59% across the operating bandwidth. The reason for low radiation efficiency is htat it is out of phase with current at high frequency as shown in Fig. 3(c). Compared with the traditional dipole antennas in Refs. [17] and [18], the proposed antenna has relatively good radiation performance, high gain or efficiency.

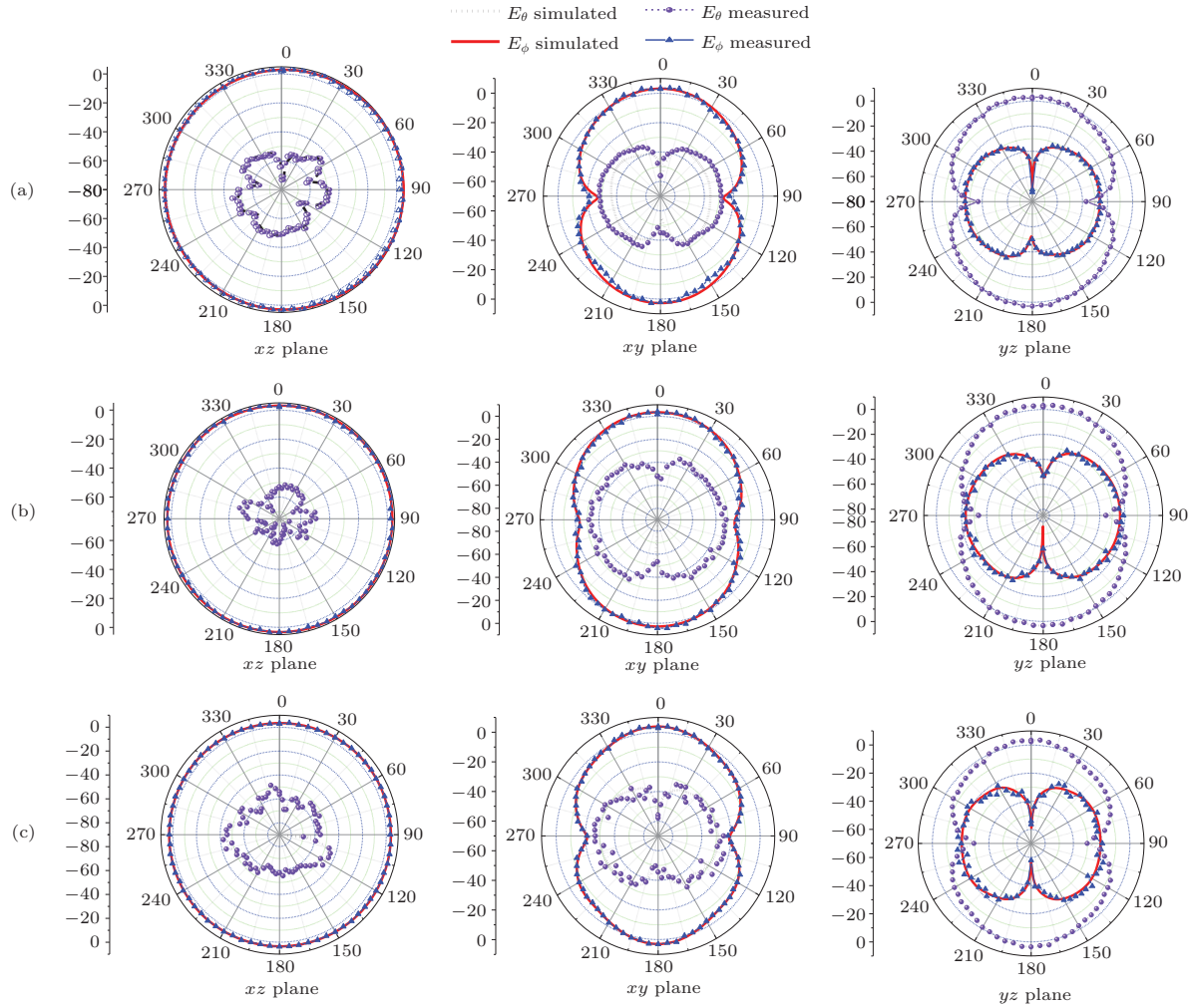


Fig. 5. (color online) Comparison between simulated and measured radiation patterns at (a) 4 GHz, (b) 5 GHz, and (c) 6 GHz.

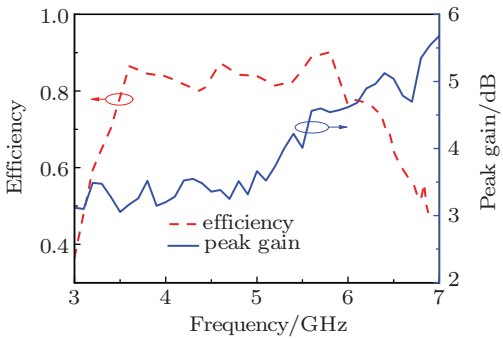


Fig. 6. (color online) Measured efficiency and gain against frequency of the proposed dipole antenna.

5. Conclusion

A novel dipole antenna structure with inter-digital capacitor is designed, fabricated, and tested. This antenna is found to exhibit characteristics of wide bandwidth operation from 3.9 GHz–6.6 GHz, corresponding to 51% bandwidth. It also has stable directional radiation patterns. Moreover, the measured total efficiency is larger than 59% across the band width with reasonable gain performances. This new kind of dipole antenna is expected to be used for the wideband wireless communication systems in modern and future.

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