Broadband design of U-shaped folded dipole antenna for WiMAX by using characteristic mode analysis

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Abstract: In this study, we utilize an effective method called Characteristic Mode Analysis (CMA) to analyze the physical mechanisms of U-shaped Folded Dipole Antenna (UFDA), which have been proposed for WiMAX device. The proposed antenna consists of the UFDA element and small Ground Plane. As a result, it is confirmed that two types of modes in the resonance of UFDA appear, the one is the mode of the Ground Plane and the other is the mode of the UFDA element. Subsequently, from these results, an easier method for broadband design of UFDA which can cover completely two frequency bands of WiMAX was investigated.

Keywords: characteristic mode analysis, U-shaped folded dipole antenna, broadband, WiMAX

Classification: Antennas and Propagation

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1 Introduction

To enhance the communication quality for wireless devices, the built-in antennas have been required to cover a wider bandwidth with a further compact design. Therefore, the design of antennas that have broadband characteristics is one of the most important concepts in antenna development for wireless devices. In the previous study, we have proposed a U-shaped folded dipole antenna (UFDA) composed of an UFDA element and a ground plane (GP) with small size which could be installed inside a wireless device for worldwide interoperability for microwave access (WiMAX). By using a suitable objective function in a particle swarm optimization (PSO), the designed UFDA covered dual frequency bands from 2.3 GHz to 2.7 GHz and from 3.4 GHz to 3.8 GHz for $S_{11} \leq -6$ dB. Furthermore, the occupancy area of the antenna was reduced to 23.1% of the previous optimized UFDA [1]. Although the final shape of the antenna could be only obtained by the PSO design, the physical mechanism of the antenna was not clear.

In this study, the characteristic mode analysis (CMA) is utilized as an effective method for the broadband design while understanding the physical mechanism of each part of the UFDA element and the GP [2, 3]. First, the characteristic modes of the UFDA on the GP are analyzed. After considering the physical mechanism of each part of the UFDA element and the GP, the antenna is designed to cover completely dual frequency bands of the WiMAX.

2 Antenna structure and CMA result

In this study, the simulator CST-MW STUDIO is used and the antenna is made of perfect electric conductor (PEC) for the analysis. Firstly, two parts of the antenna (UFDA element only and GP) are separated and analyzed independently. After determining the resonant frequencies and characteristics (broadband or narrow-band) of modes of these separated parts, we combine them to return the initial model, then analyze with CMA. A mode will be defined as a resonance when its model significance (MS) value $= 1$ [4].

Fig. 1(a) shows the GP with the overall length of 75 mm x 31 mm and its MS. The modes are tracked from 1.0 to 5.5 GHz including frequency bands of WiMAX. Two resonances appear at the frequency of 1.7 GHz (Mode1) and 3.9 GHz (Mode2) and both of them have wide bandwidth defined by $MS > 0.707$ [5]. The antenna element has a folded dipole antenna bent into U-shape with detailed dimensions and its MS are shown in Fig. 1(b). As can be seen, three resonances at the frequency of 1.8 GHz (Mode3), 2.8 GHz (Mode4) and 5.1 GHz (Mode5) appear after analyzing the UFDA element only. By comparing the bandwidth of mode between GP only and UFDA element only, we know that, three resonances of UFDA element only have narrower bandwidth than the resonances of the GP only. Fig. 1(c) shows the MS of the combined model of the GP and the UFDA element without feeding. By analyzing the combined model, four resonances are defined including 1.9 GHz (Mode1), 3.2 GHz (Mode2), 2.5 GHz (Mode3) and 4.4 GHz (Mode4). With the same way to examine the characteristics of each resonance, we can realize that Mode1 and Mode2 of the combined model have wide bandwidth similar to Mode1 and Mode2 of the GP only shown in Fig. 1(b). Meanwhile,
Mode 3 and Mode 4 of the combined have narrower bandwidth, similar to Mode 3 and Mode 4 of the UFDA element only shown in Fig. 1(c).

3 Consideration

By observing these bandwidth similarities in the aspect of modes, we could recognize which mode is mostly influenced by which separated part of antenna. However, the mode of each part shifted to different frequency when the UFDA element and the GP are combined. Thus, the validity of them are needed to be confirmed by comparing the surface current distribution at each resonant frequency of mode between separated parts and the combined model.

Fig. 2(a) shows the surface current distribution of GP only at 1.7 GHz (Mode1) and of the combined model at 1.9 GHz (Mode1). Fig. 2(b) shows the surface current distribution of GP only at 3.9 GHz (Mode2) and of the combined at 3.2 GHz (Mode2). It can be seen that the locations of current maxima or minima are at the same position and the direction of the currents are also similar to both of GP. This verified that mode 1 and mode 2 is the mode of the GP.

Fig. 2(c) shows the surface current distribution of UFDA element only at 1.8 GHz (Mode3) and of the combined model at 2.5 GHz (Mode3). Fig. 2(d) shows the surface current distribution of UFDA only at 2.5 GHz (Mode4) and of the combined model at 4.4 GHz (Mode4). We can see that the surface current

Fig. 1. The structure of UFDA and CMA results
distributions are similar on the UFDA element and the directions are in the same direction to each other. For that reason, we could conclude that mode 3 and mode 4 are the modes of the UFDA element.

The simulated reflection coefficient of the combined model after feeding is indicated as Fig. 2(e). The UFDA element is fed by a 50Ω source at feeding strip, and connected to the GP at the shorting strip. As can be seen, three resonances appear at 1.8GHz, 2.6GHz and 3.4GHz, and they have the same resonant frequency of Mode 1, Mode 3 and Mode 2 in CMA result, respectively. Thus, the validity of CMA result was confirmed. For convenience, we call these resonances by the first, the second and the third resonance, respectively. By comparing with the result of CMA, we know that the first and third resonance are associated with mode 1 and mode 2 of GP. Meanwhile, the second one is associated with mode 3 of the UFDA element. Moreover, the gray ranges in Fig. 2(e) present two frequency bandwidths of WiMAX and they are not covered completely for $S_{11} \leq -6$ dB. Therefore, in order to cover completely these frequency bandwidths, the shape of GP should be adjusted to the first and third resonance shifting to higher frequency, while, the shape of UFDA element should be adjusted to the second resonance shifting to lower frequency.

(a) Current distributions of the GP only (1.7 GHz) and the combined model (1.9 GHz)

(b) Current distributions of the GP only (3.9 GHz) and the combined model (3.2GHz)

(c) Current distributions of the UFDA element only (1.8 GHz) and the combined model (2.5 GHz)

(d) Current distributions of the UFDA element only (2.5 GHz) and the combined model (4.4 GHz)
4 Antenna design

Fig. 3(a) shows the design for GP only, which mostly affected mode 1 and mode 2 of CMA result. By observing the common position of maximum current distribution on the GP shown in Fig. 2(a) and Fig. 2(b), two parts on the GP are trimmed with a dimension of 10 mm × 5 mm. Therefore, resonant frequency of mode 1 and mode 2 could be shifted to higher frequency. While, for the UFDA element only, resonant frequency of mode 3 shift to lower frequency when a center part of the UFDA element is reduced from 4 mm to 2 mm, as shown in Fig. 3(b). After obtaining two separated parts with desired design, the new UFDA is combined and its CMA result is shown in Fig. 3(c). As can be seen that the resonant frequencies of mode 1 and mode 2 shift to higher frequency (2.1 GHz and 3.3 GHz, respectively), the resonant frequency of mode 3 shifts to lower frequency (2.3 GHz) than previous UFDA shown in Fig. 1(d).

The validity of the simulated results were confirmed by measured reflection coefficient of UFDA after designing, shown in Fig. 3(d). Therefore, the bandwidth with $S_{11} \leq -6$ dB is wider than previous result from 2 GHz to 2.7 GHz and from 3.3 GHz to 3.9 GHz, which could cover completely the WiMAX frequency bands. From Fig. 3(e), a good agreement is observed between the simulated and measured radiation pattern in the $yz$ plane.

(a) Design for the GP only

(e) Simulated reflection coefficient of the combined model

Fig. 2. The comparison of current contributions and simulated reflection coefficient of the combined.
5 Conclusion

In this study, by utilizing the advantageous features of CMA to analyze each part of the antenna, we gave further illustrations of the physical mechanism of UFDA. It is confirmed that there are two types of modes in resonances. The first one consists of two modes at 1.9 GHz and 3.2 GHz, affected mostly by the GP. While, the other includes two modes at 2.5 GHz and 4.4 GHz, mainly affected by the UFDA element. From these results, we investigated an easier method to help UFDA have broadband characteristic. By trimming and reducing suitably position of the maximum surface current on the GP and UFDA element, respectively, two frequency bands of WiMAX could be completely covered for $S_{11} \leq -6$ dB.