Dimension optimization of U-Shaped Folded Dipole Antenna for WiMAX by using PSO

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Abstract

This paper introduces the method of applying Particle Swarm Optimization to optimize the dimension parameters of U-Shaped Folded Dipole Antenna element on a small ground plane to cover two using frequency bands of WiMAX (2.3~2.7 GHz and 3.4~3.8 GHz) based on IEEE 802.16 standardization.

Keywords : Folded Dipole Antenna WiMAX Particle Swarm Optimization

1. Introduction

As reported previously [1] , we have proposed a method to apply U-Shaped Folded Dipole Antenna (UFDA) on a small rectangular ground plane (GP) as an antenna for WiMAX USB dongle. The method is that to eliminate a part of GP, and as a result, when a part of GP right under the UFDA element is cut properly, two using frequency bands of WiMAX (2.3~2.7 GHz and 3.4~3.8 GHz) for VSWR≤3 are covered and a wideband characteristic of UFDA is achieved. Moreover, the most effective way of cutting GP has been found when a much wider covered band of UFDA is obtained with the smallest cutting area by adopting Particle Swarm Optimization (PSO) [2]. In this study, we try to cover these two using frequency bands of WiMAX for VSWR≤3 (S_{11}≤–6 dB) here again without cutting GP. According to that, the purpose of this paper is to investigate the possibility of applying PSO to optimize the dimension parameters of UFDA element, only.

2. Dimension Parameters of UFDA

Figure 1 shows the structure of the antenna where UFDA element is placed along the upper end of a 75 mm×31mm GP. UFDA is a folded dipole element bended into U-shape, which is fed by a coaxial cable at the feed strip and connected to GP at the short strip. Both the feed strip and short strip have the same width $\boldsymbol{w}_1$ and the distance between them is defined as $\boldsymbol{g}$. The lower antenna element has a gap of $\boldsymbol{p}$ at the center and then, the requisite relation for $\boldsymbol{p}$ and $\boldsymbol{g}$ is that $\boldsymbol{p} \leq \boldsymbol{g}$ as written in inequation (5). The distance between the upper and lower antenna elements is $\boldsymbol{b}$ and the height from the lower element to GP is $\boldsymbol{h}$. Both the upper and lower elements have the same width $\boldsymbol{w}_2$ in the direction of ***Ox*** axis and the same width $\boldsymbol{w}_3$ in the direction of ***Oy*** axis. The length of two folded parts is defined as $\boldsymbol{l}$. All these 8 dimension parameters ($\boldsymbol{b}$, $\boldsymbol{h}$, $\boldsymbol{w}_1$, $\boldsymbol{w}_2$, $\boldsymbol{w}_3$, $\boldsymbol{l}$, $\boldsymbol{p}$, $\boldsymbol{g}$) of UFDA element are set up as 8 variables and enlarged in the left side of Fig.1 to show detail.

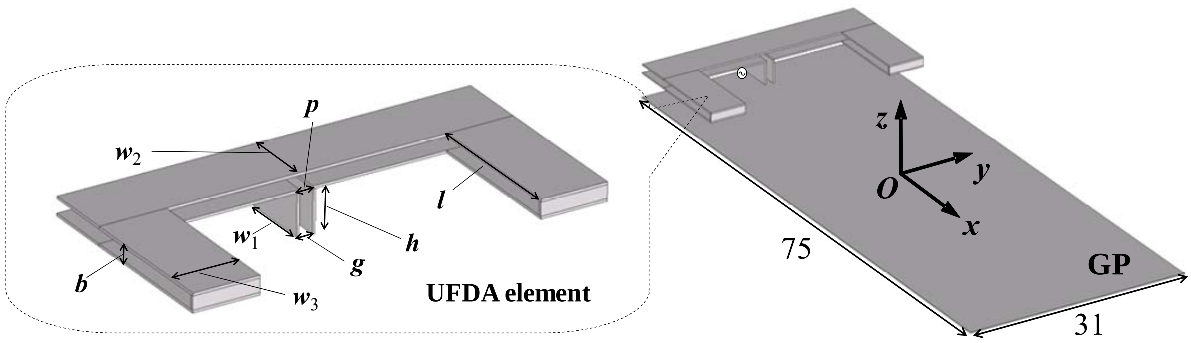


Figure 1: UFDA element on GP

For maintaining U-shape folded form of UFDA element during the optimization process and making the mounting space of UFDA element not extend so much, the constraint conditions for these 8 variables are determined as following:

$$\boldsymbol{b} + \boldsymbol{h} \leq 5 \tag{1}$$

$$1 \leq \boldsymbol{w}_1, \boldsymbol{w}_2, \boldsymbol{w}_3 \leq 7 \tag{2}$$

$$1 \leq \boldsymbol{l} \leq 20 \tag{3}$$

$$1 \leq \boldsymbol{p}, \boldsymbol{g} \leq 21 \tag{4}$$

$$\boldsymbol{p} \leq \boldsymbol{g} \tag{5}$$

All these 8 variables are set up at 0.1 mm intervals. The most optimal combination of them ($\boldsymbol{b}_{\text{best}}$, $\boldsymbol{h}_{\text{best}}$, $\boldsymbol{w}_{1\text{best}}$, $\boldsymbol{w}_{2\text{best}}$, $\boldsymbol{w}_{3\text{best}}$, $\boldsymbol{l}_{\text{best}}$, $\boldsymbol{p}_{\text{best}}$, $\boldsymbol{g}_{\text{best}}$) will be chosen by applying the algorithm of PSO to accomplish the goal we target.

3. PSO Application Method and Result

PSO has the simple algorithm that imitates the swarm action of birds or insects. Each particle is considered as a bird in a swarm consisted of $\boldsymbol{M}$ birds, and the algorithm is characterized by renewing coordinates and velocities of every particle in the swarm. If $\boldsymbol{x}_{\text{i}}(\boldsymbol{k})$ and $\boldsymbol{v}_{\text{i}}(\boldsymbol{k})$ are the coordinate and velocity of particle number $\boldsymbol{i}$ ($1 \leq \boldsymbol{i} \leq \boldsymbol{M}$) at step $\boldsymbol{k}$, they are updated into their new values at step $\boldsymbol{k}$+1 as $\boldsymbol{x}_i(\boldsymbol{k}+1)$ and $\boldsymbol{v}_i(\boldsymbol{k}+1)$ by applying two equations below:

$$\boldsymbol{v}_i(\boldsymbol{k}+1) = \boldsymbol{\omega}\boldsymbol{v}_i(\boldsymbol{k})+\boldsymbol{c}_1\boldsymbol{r}_1[\boldsymbol{p}_i(\boldsymbol{k}) - \boldsymbol{x}_i(\boldsymbol{k})]+\boldsymbol{c}_2\boldsymbol{r}_2[\boldsymbol{p}_g(\boldsymbol{k}) - \boldsymbol{x}i(\boldsymbol{k})] \tag{6}$$

$$\boldsymbol{x}_i(\boldsymbol{k}+1) = \boldsymbol{x}_i(\boldsymbol{k}) + \boldsymbol{v}_i(\boldsymbol{k}+1)\Delta\boldsymbol{t} \tag{7}$$

where $\boldsymbol{p}_i(\boldsymbol{k})$ and $\boldsymbol{p}_g(\boldsymbol{k})$ are the best coordinates of particle number $\boldsymbol{i}$ and the whole swarm until step $\boldsymbol{k}$, respectively. Both $\boldsymbol{r}_1$ and $\boldsymbol{r}_2$ get independent random values inside [0;1] and according to reference [3], the suitable values of all the parameters in (6) and (7) are that $\boldsymbol{c}_1$=1.5, $\boldsymbol{c}_2$=2.5, $\Delta\boldsymbol{t}$ =0.7, $\boldsymbol{\omega}$:1.4~0.35.

When applying PSO to optimize the shape of UFDA, we choose here $\boldsymbol{M}$=30 and suppose that one form (one shape) of UFDA element (decided by one combination ($\boldsymbol{b}$, $\boldsymbol{h}$, $\boldsymbol{w}_1$, $\boldsymbol{w}_2$, $\boldsymbol{w}_3$, $\boldsymbol{l}$, $\boldsymbol{p}$, $\boldsymbol{g}$)) is one particle (one bird) of the swarm. In other words, for one form of UFDA element, 8 variables $\boldsymbol{b}$, $\boldsymbol{h}$, $\boldsymbol{w}_1$, $\boldsymbol{w}_2$, $\boldsymbol{w}_3$, $\boldsymbol{l}$, $\boldsymbol{p}$, $\boldsymbol{g}$ are transformed and expressed by 8 components $\boldsymbol{x}_{i1}$, $\boldsymbol{x}_{i2}$, $\boldsymbol{x}_{i3}$, $\boldsymbol{x}_{i4}$, $\boldsymbol{x}_{i5}$, $\boldsymbol{x}_{i6}$, $\boldsymbol{x}_{i7}$, $\boldsymbol{x}_{i8}$ which are components of the coordinate $\boldsymbol{x}_i$ of particle number $\boldsymbol{i}$ in (6) and (7). Each form of UFDA element is analyzed in the frequency band 0~10 GHz at 0.01 GHz intervals. At two using frequency bands of WiMAX (2.3~2.7 GHz and 3.4~3.8 GHz), the frequencies which satisfy the condition $S_{11} \leq -6$ dB are counted, then the number of those frequencies is assumed to be $\boldsymbol{N}$. Objective function $\boldsymbol{F}$ for optimization process is defined as below:

$$\boldsymbol{F} = -\boldsymbol{N} \tag{8}$$

It is clear to see the maximum of $\boldsymbol{N}$ is $\boldsymbol{N}_{max}$ = 82 when function $\boldsymbol{F}$ is minimized to reach its minimum as $\boldsymbol{F}_{min}$ = –82, and the optimal shape of UFDA will be obtained in this case. The minimization of $\boldsymbol{F}$ done by PSO algorithm through 55 steps is shown in Fig.2.

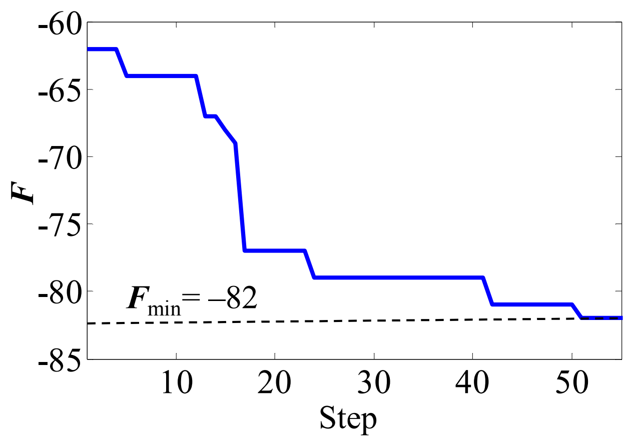
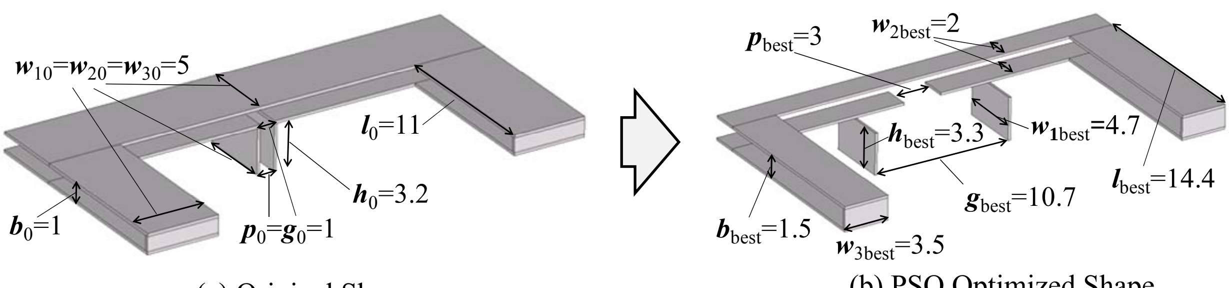


Figure 2: Convergence of objective function $\boldsymbol{F}$



(a) Original Shape

(b) PSO Optimized Shape

Figure 3: Shape of UFDA element

Figure 2 shows that $\boldsymbol{F}$ converges to –82 from the 51th step. This also means that two using frequency bands of WiMAX are covered for $S_{11} \leq -6$ dB completely with the best shape of UFDA element among $\boldsymbol{M}$=30 cases from 51th step. This best shape is "PSO Optimized Shape" shown in Fig.3(b) compared to the "Original Shape" in Fig.3(a). We can see obviously that the "PSO Optimized Shape" is smaller than the "Original Shape" when all three width parameters w_1, w_2, w_3 is decreased properly to their most adequate values. The gap $\boldsymbol{p}$ at the center of lower antenna element and the disctance $\boldsymbol{g}$ between the feed strip and the short strip are also widened adequately to achieve the good impedance characteristic as shown by the red line in Fig.4. After being optimized by PSO, UFDA element not only has two using frequency bands of WiMAX covered, but also has a wideband characteristic in 2.25~3 GHz band.

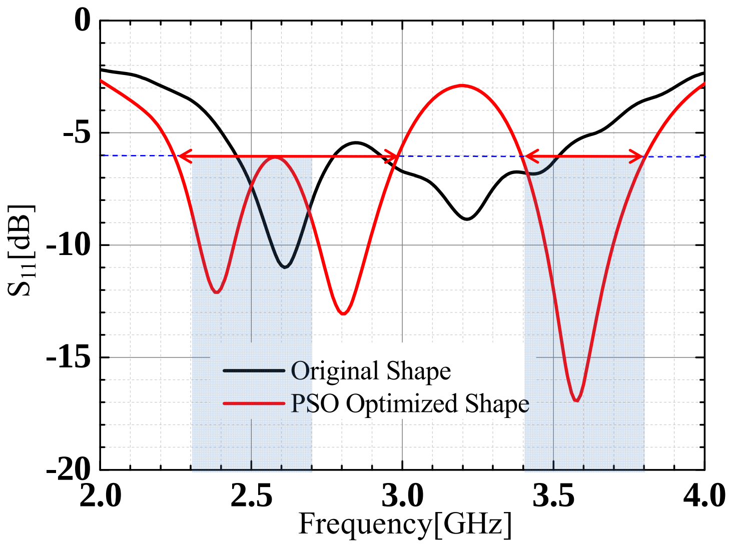


Figure 4: Input impedance characteristics

4. Conclusion

In this study, in order to cover two using frequency bands of WiMAX, PSO is used to optimize the shape of UFDA element. We can conclude that it is possible to cover two using frequency bands of WiMAX by applying PSO to UFDA element only and without adjusting GP. In the future work, it is desirable to adopt PSO to many types of antenna for different purposes, respectively.

References

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