Sizing Optimization of Small Antenna Design by PSO Linking MATLAB and CST-Microwave Studio

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1 Introduction

In recent years, due to the magnificent development of calculation ability of computer, optimization design has been introduced and investigated in many research fields with numbers of optimization algorithms. In the field of antenna design (especially design of small antennas), most of current electromagnetic simulators also have some built-in optimization tools which can help antenna designers be possible to optimize their antennas with desirable characteristics. However, there is a limit of these tools which is that users can not express their optimization purposes in details by formulating objective functions, which is requisite for every optimization problems. Therefore, in the case of optimization problems requiring complicated settings of objective function, it is preferable to formulate objective function in a programming environment.

This paper presents a method of linking programming language MATLAB [1] and electromagnetic simulator CST-microwave studio (CST-MWS) [2], and then apply both of these to sizing optimization problem of small antenna design by using particle swarm optimization (PSO) [3]. Firstly, the concept of PSO and the method of implementing PSO to small antenna optimization design by MATLAB and CST-MWS will be described. Secondly, as a quoted example, this implementation will be introduced to optimization design of U-shaped folded dipole antenna (UFDA) [4] which is assumed to be used inside an USB dongle for WiMAX (worldwide interoperability for microwave access).

2 PSO Calculation by Linking MATLAB and CST-Microwave Studio

Particle swarm optimization (PSO) is based on a simplified social model of swarming theory. The flowchart of implementing PSO in antenna design is shown in Fig. 1. In an optimization problem with the design variable $\boldsymbol{X}$ and the objective function $\boldsymbol{G}(\boldsymbol{X})$ deal with PSO, coordinate and velocity of each particle are put to $\boldsymbol{X}$ and $\boldsymbol{V}$ respectively, and both $\boldsymbol{X}$ and $\boldsymbol{V}$ are renewed sequentially by exchanging searching information among all particles in the swarm. At each step, optimality of coordinate $\boldsymbol{X}$ of every particles is evaluated by the objective function $\boldsymbol{G}(\boldsymbol{X})$, and the particle which has the best objective function value as $\boldsymbol{G}(\boldsymbol{X}_{\text{elite}})$ is defined as elite particle. The coordinate $\boldsymbol{X}_{\text{elite}}$ of elite particle is selected at each step, and this selection is repeated until $\boldsymbol{G}(\boldsymbol{X}_{\text{elite}})$ is not renewed. When $\boldsymbol{G}(\boldsymbol{X}_{\text{elite}})$ converges to a constant value, the final coordinate $\boldsymbol{X}_{\text{elite}}$ at the last step is considered as the optimal solution $\boldsymbol{X}_{\text{opt}}$ of optimization problem. In Fig. 1, "Model analysis" is executed by CST-MWS, and the other ones are executed by MATLAB to make the PSO program run continuously.

3 Example of Applying PSO to Optimize U-Shaped Folded Dipole Antenna for WiMAX

3.1 Fundamental Antenna Model

Figure 2 shows the original model of UFDA on a 75 mm × 31 mm GP which represents the shielding plate inside USB dongle. UFDA is connected to GP by the short strip, and fed from GP to its feed strip by a coaxial cable. UFDA has been already reported as a wideband antenna for WiMAX [4]. When an area about 3.8% of GP is cut, UFDA can cover a wide frequency band including two WiMAX bands (2.3~2.7 GHz and 3.4~3.8 GHz). Here, we adopt PSO to optimize respectively the cutting shape of GP, and the shape of UFDA element when GP is not cut, by applying two efficient objective functions to PSO. For optimizing the cutting parameters of GP (case 1), or the dimension parameters of UFDA (case 2), we consider these parameters as continuous design variables and put them to components of coordinate $\boldsymbol{X}$ of every particles in the swarm of PSO. Two respective objective functions for each case are designed as below.

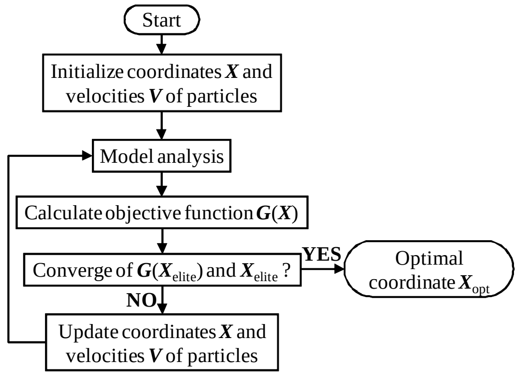

Fig. 1. Flowchart of PSO.

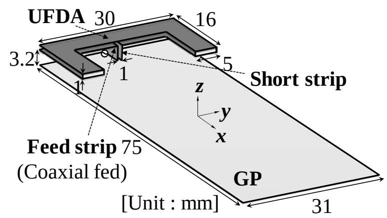

Fig. 2. Configuration of fundamental antenna model.

3.2 Optimization of cutting GP (case 1)

Here, the fundamental shape of UFDA is maintained during the optimization of cutting GP. Cutting GP is decided by three cutting parameters, and the design target in this case is to obtain both a wider resonance band (VSWR≤3) and a smaller cutting area than 3.8%. Therefore, the objective function $\boldsymbol{G}1(\boldsymbol{X})$ of this problem is proposed as in Equation (1).

$$\boldsymbol{G}1(\boldsymbol{X}) = (\text{VSWR}_1+\text{VSWR}_2+\text{VSWR}_3)/6 + [\boldsymbol{S}_{\text{cut}}/2\boldsymbol{S}_0] \qquad (1)$$

In Equation (1), VSWR_1, VSWR_2, VSWR_3 are the values of VSWR at three frequencies $\boldsymbol{f}_1$=2.5 GHz, $\boldsymbol{f}_2$=3.05 GHz, $\boldsymbol{f}_3$=3.6 GHz where $\boldsymbol{f}_1$ and $\boldsymbol{f}_3$ are two center frequencies of two WiMAX bands, and $\boldsymbol{f}_2$ is the center frequency between $\boldsymbol{f}_1$ and $\boldsymbol{f}_3$. The cutting area $\boldsymbol{S}_{\text{cut}}$ of GP is normalized with the criterion value $\boldsymbol{S}_0$=100 mm^2. It is assumed that minimizing $\boldsymbol{G}1(\boldsymbol{X})$ by PSO will help all VSWR_1, VSWR_2, VSWR_3 and $\boldsymbol{S}_{\text{cut}}$ to be minimized simultaneously, where the reductions of VSWR_1, VSWR_2,

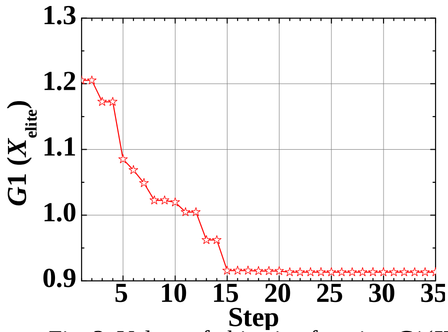

Fig. 3. Values of objective function $\boldsymbol{G}1(\boldsymbol{X}_{\text{elite}})$.

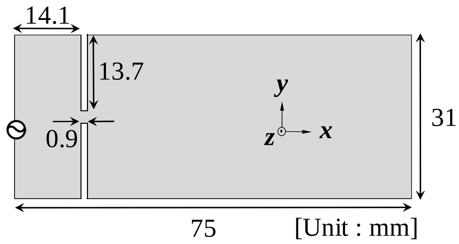

Fig. 4. Optimal shape of ground plane.

VSWR$_3$ are expected to be equal to achieving a wide resonance band. That is to say, minimizing $\boldsymbol{G}1(\boldsymbol{X})$ makes the design target be attained.

The convergence of objective function $\boldsymbol{G}1(\boldsymbol{X})$ in PSO is decided by Elite particle which has the best coordinate $\boldsymbol{X}_{\text{elite}}$ in the swarm at each step. Figure 3 shows the convergence of $\boldsymbol{G}1(\boldsymbol{X}_{\text{elite}})$ through 35 steps where $\boldsymbol{G}1(\boldsymbol{X}_{\text{elite}})$ is minimized to its minimum value as 0.91. This minimum value of $\boldsymbol{G}1(\boldsymbol{X}_{\text{elite}})$ leads to the optimal shape of GP as shown in Fig. 4 with three cutting parameters optimized to 14.1, 0.9 and 13.7 mm, respectively. According to this, the cutting area $\boldsymbol{S}_{\text{cut}}$ here is minimized to 24.7 mm^2 which is only 1% area of original shape of GP. Figure 7 shows the comparison of calculated VSWR characteristics before and after optimizing. After optimizing the cutting shape of GP (the red line with star marks), resonance band of UFDA is widen much more with the relative bandwidth about 64% (VSWR≤3 in 2.35~4.38 GHz). This result indicates that the design target of this case is accomplished perfectly when both wideband characteristic and small cutting area are obtained simultaneously.

3.3 Optimization of UFDA Element (case 2)

In this case, we investigate how to optimize the shape of UFDA element without cutting GP. Shape of UFDA element is designed with 8 dimension parameters, and the design target here is just to cover two WiMAX bands (VSWR≤3 in 2.3~2.7 GHz and 3.4~3.8 GHz). Here, if we adopt function $\boldsymbol{G}1(\boldsymbol{X})$ with $\boldsymbol{S}_{\text{cut}}$=0 to PSO like in case 1, there is a possibility that VSWR may decrease enormously at only one frequency and increase over 3 at other frequencies. Therefore, the objective function $\boldsymbol{G}2(\boldsymbol{X})$ adopted to PSO in this case is defined as the following Equation (2).

$$\boldsymbol{G}2(\boldsymbol{X}) = -\boldsymbol{N}_{\text{f}} \tag{2}$$

In Equation (2), $\boldsymbol{N}_{\text{f}}$ is the number of frequency points in two WiMAX bands which satisfy the condition VSWR≤3. Two bands of WiMAX are divided to 82 frequency points (10 MHz interval) and so on, the maximum value of $\boldsymbol{N}_{\text{f}}$ is 82. It is assumed that by using PSO to minimize $\boldsymbol{G}2(\boldsymbol{X})$ to −82, an optimal shape of UFDA element that fulfills the design target in this case will be obtained.

The minimization of $\boldsymbol{G}2(\boldsymbol{X})$ done by Elilte particle through 51 steps is shown in Fig. 5 where $\boldsymbol{G}2(\boldsymbol{X}_{\text{elite}})$ gets to -82 at 51$^{\text{st}}$ step. According to this, the optimal shape of UFDA is formed as in Fig. 6 with its 8 dimension parameters optimized to 1.5, 3.3, 10.7, 3, 4.7, 2, 3.5, 14.4 mm, respectively. Since the width of every parts of UFDA become smaller after optimizing, this

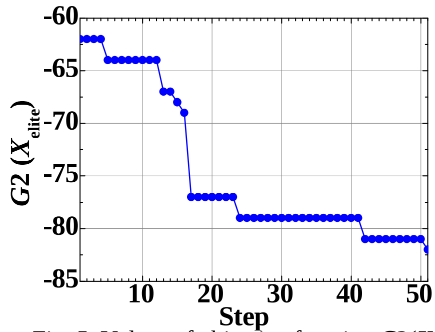

Fig. 5. Values of objective function $\boldsymbol{G}2(\boldsymbol{X}_{\text{elite}})$.

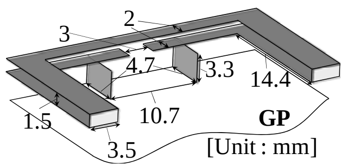

Fig. 6. Optimal shape of UFDA element.

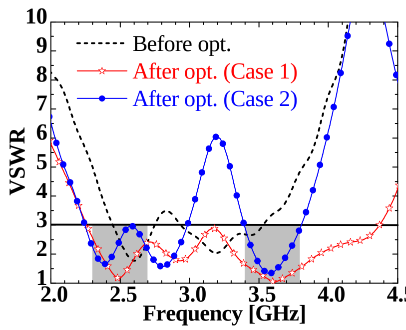

Fig. 7. VSWR characteristics before and after optimizing.

optimal shape has the volume as 72% when compared to its original shape, which means that it is effective for miniaturizing antenna size. Moreover, the blue line with circle marks in Fig. 7 indicates that after optimizing UFDA element, two WiMAX bands are covered completely (VSWR≤3 in 2.24~2.99 GHz and 3.39~3.81 GHz). That is to say, the design target is also achieved perfectly in this case.

4 Conclusion

In this study, as a quoted example of small antenna optimization design by linking MATLAB and CST-MWS, we have investigated optimization of UFDA design for WiMAX. By adopting two objective functions to PSO to optimize respectively the shapes of GP and UFDA have been proposed by two different effective formulations. First, in the case of optimizing the cutting shape of GP with the shape of UFDA maintained, using a combined function that can evaluate both VSWR value and the cutting area has helped to form an optimal shape of GP with smallest cutting area as 1% and obtain a 64% bandwidth including two WiMAX bands. Next, in the case of optimizing UFDA without cutting GP, using a function that counts the number of frequency points satisfying VSWR≤3 has helped to form an optimal shape of UFDA which has the volume as 72% of its original shape but can cover completely two WiMAX bands. Therefore, effectiveness of two objective functions are demonstrated obviously.

References

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