Design of E-patch Conformal Antenna on Conical Surface through Space Mapping Optimization

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I. Introduction

Conformal antenna has several advantages: less influence on platform's aerodynamic factor, less space for installation, large scan range and so on. In the past twenty years, conformal antenna has promoted the development of commercial and military application. For instance, satellite communication [1], mobile communication and public safety [2] etc. However, when the classic antennas are used to design conformal ones, it is inevitable to find that the characteristics of antennas would change due to the effect of the platform. Taking patch antenna as an example, to design a conformal patch antenna by using original empirical equation is not appropriate in most condition. So that designing and optimizating the conformal antenna would become a formidable task. In order to solve this problem, space mapping is adopted to optimize the conformal antenna.

Space mapping algorithm is firstly introduced by Jone W. Bandler for microwave circuit optimization [3]. With the development of theory of space mapping, more and more effective methods [4, 5] have been proposed. Furthermore, the application of space mapping has expanded its application area into antenna [6]. However, there is little report about conformal antenna design by using space mapping.

In this paper, it is represented that an array consisted by three E-patch elements which are aligned along the cone's generatrix (shown in Fig. 1). And its operating band is from 12GHz to 18GHz (|S11|<-10dB). Simulation results show the result of optimization.

II. Basic of Space Mapping Optimization

For eliminating this paper clearly, it is necessary to introduce the basic theory of space mapping. The space mapping is a kind of indirect optimization by contrast with direct optimization such as quasi-Newton method or genetic algorithm. The key point of the SM is to find appropriate transformation between coarse model and fine model. The fine model means that the model is computationally expensive during simulation process. But the fine model has more exact simulation result than the coarse one. Hence, compared with the fine model, the coarse model is a computationally cheap but inaccurate model. It is assumed that time and resource required by direct optimization of fine model is always intolerable and direct optimization may be failed to provide the acceptable result sometimes. But through SM, with the optimal solution of coarse model, the optimal result of coarse model will be received with several times computation of coarse model and few times computation of fine model.

Let x_c , x_f respectively denote the parameter of coarse and fine model. As it is mentioned before, the key idea of SM is to find a transformation which will satisfy equation 1 as follow:

$$x_c = P(x_f) \quad (1)$$

Such that

$$\| R_f(x_f) - R_c(x_c) \| \le \varepsilon \quad (2)$$

P is the established mapping between the coarse model and the fine one. R_f and R_c respectively denote the coarse and fine model responses. With the constraint of (2), the mapping P could be found by several times of iteration of parameter extraction. The step of parameter extraction plays a significant role in the procedure of SM and it need direct optimization to fulfil this step. In this paper, we apply the quasi-Newton [7] method in parameter extraction. Thus, P^i denotes the approximation to P at the i th iteration. And the corresponding solution of fine model is obtained by

$$x_f^{i+1} = P^{(i)^{-1}}(x_c^*) \quad (3)$$

Where x_c^* denotes the optimal coarse model solution. If x_f^{i+1} satisfies a certain termination criterion such as equation (4), it is accepted as the optimal fine model solution $\overline{x}_f$ in (5)

$$\| R_f(x_f^{i+1}) - R_c(x_c^*) \| \le \varepsilon \quad (4)$$

$$\overline{x}_f = P^{-1}(x_c^*) \quad (P = P^{(i)-1}) \quad (5)$$

P^{-1} is the inverse mapping, when the mapping (1) is established. Otherwise the mapping is updated.

III. Simulation results

We consider the design of E-patch conformal antenna array shown in Fig. 1 and use the planar E-patch antenna array as coarse model shown in Fig. 2 for the SM. The geometries of E-patch element are presented (shown in Fig. 3) as follow: $\varepsilon_r = 2.55$, height h=1.5 mm, L=12.9 mm，W=w+3.5 mm, w=2.58 mm, pf=1 mm, p1=4.8 mm, p2=1.8mm and the dimension of the ground is 70 mm*36 mm. And the distance of each element is 20mm. w,p1,p2 are considered as optimization variable. For verifying the feasibility of planar antenna array as coarse model, we optimize only an individual E-patch conformal antenna element at first. Both the coarse and fine models for the SM are shown in Fig. 4.The reflection coefficient as follow is chosen as object function and the object function is calculated at frequencies from 12GHz to18GHz($|S_{11}| \le -10$ dB). Fig. 5 contains the results of optimal coarse model, initial fine model and solution of fine model through the SM. Parts of the curves inside the red circle indicates the places where the initial fine model could not fulfil the requirement and where the optimal fine model could satisfy the specification after the SM. And the solutions are listed in Table 1.So that, the result indicates that it is sensible to apply planar E-patch as coarse model to optimize the conformal antenna array through SM. As we known, the element in array has the effect of mutual coupling. Thus, in order to receive a more exact mapping in the process of array optimization, corresponding element of coarse model will be chosen as different element of the fine mode need optimization. For example, the upper element of planar is chosen, when we optimize the upper one of fine mode, because their characteristics of mutual coupling are similar. Fig 6 plots the $|S_{11}|$ response of best result and several steps during the process of optimizing the upper element in conformal array. Additionally, Fig 7 shows same information about optimizing the middle one. Table 2 and 3 lists the initial and final design of them respectively. The result in Figures indicates that the response of conformal has been improved by SM. And the best results of the two examples basically reach the specification. From these results, it could be drawn a conclusion that the SM would be also suitable for the optimization of E-patch conformal array on conical surface. Although, at the end of the high frequency, the $|S_{11}|$ is higher than -10dB. There may be two explanations on this problem. First, there is not enough iteration, so the mapping could no be desirable enough to find optimal fine model parameter. Or the method of direct optimization applied in process of parameter extraction is no accurate and effective enough., so the mapping acquired from inaccurate parameter extraction is also defective.

IV. Conclusion

Design of E-patch conformal antenna on conical surface is proposed in this paper. For exploiting the optimal planar patch antenna's result and decreasing the time of optimizing a conformal antenna directly accuracy of the proposed method, the space mapping optimization is applied. Simulation result demonstrate that this proposal is feasible.

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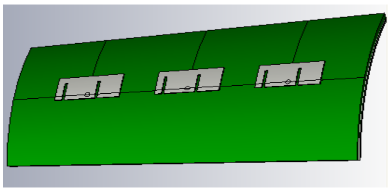

Fig. 1. E-patch conformal array
On conical surface

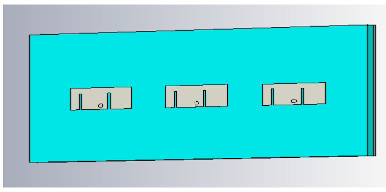

Fig. 2. E-path planar array

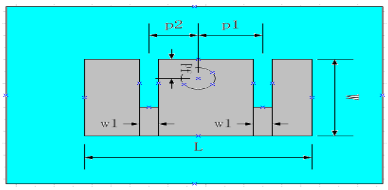

Fig.3. geometry of E-patch

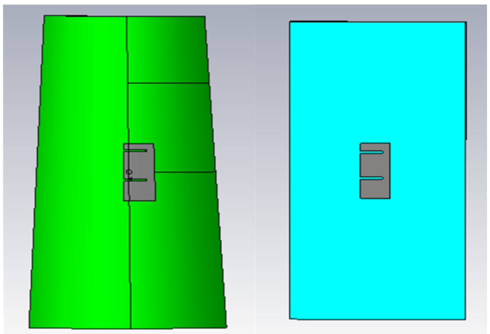

Fig.4. individual elements of coarse and fine model

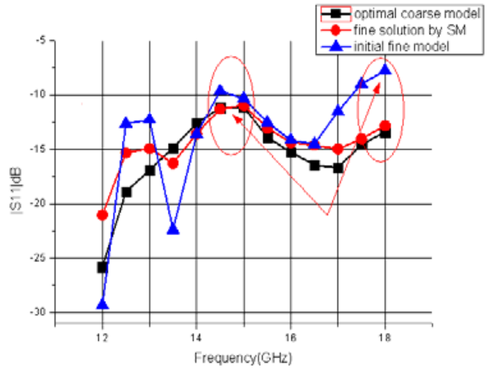

Fig.5. |S11| in the process of individual
Element optimization through SM

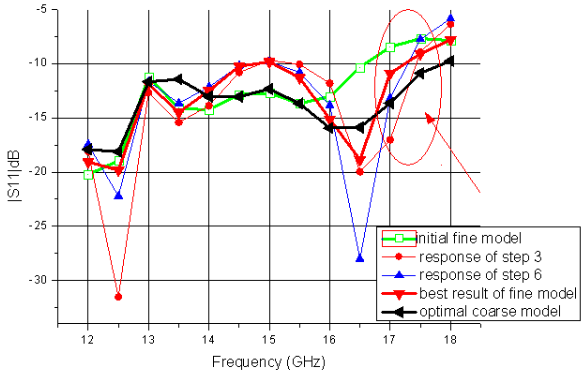

Fig.6. |S11| in the process of individual
Element optimization through SM

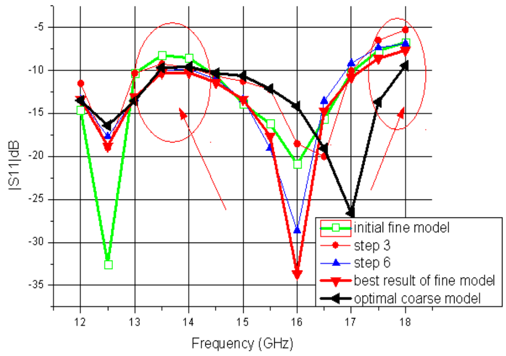

Fig. 7. |S11| in the process of middle element
Optimization through SM

Table 1: optimization result of the individual E-patch conformal antenna

Design parameter	Coarse model's Initial design (mm)	Fine model's fine design (mm)
p1	4.8	4.65
p2	1.8	1.83
w	2.58	2.5

Table 2: optimization result of the upper element

Design parameter	Coarse model's Initial design (mm)	Fine model's fine design (mm)
p1	4.6	4.54
p2	2.1	1.59
w	2.58	2.6

Table 3: optimization result of the middle element

Design parameter	Coarse model's Initial design (mm)	Fine model's fine design (mm)
p1	4.6	4.12
p2	2.1	1.88
w	2.58	2.57