Numerical Techniques for Multi-Objective Synthesis of an Inverted-S Antenna

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Abstract—**The synthesis of a dual-frequency band Inverted-S Antenna (ISA) using low profile PCB configuration is studied. To manipulate the multi-objectives and the huge amount of turning work involved in the synthesis of a dual-frequency band Inverted-S Antenna, special numerical techniques such as approaches to integrating different objectives, an improved vector genetic algorithm and a modified radial basis function based response surface model are proposed. Numerical results as reported serve to demonstrate the pros and cons of the proposed techniques.**

I. Numerical Techniques For ISA Synthesis

Nowadays, a large amount of commercial PC cards are operating at 2.4 GHz and 5 GHz. Consequently, the compact dual-frequency antenna becomes a topical research subject in both academic researches and engineering applications. In this point of view, the Inverted-S Antenna (ISA) is a promising candidate since it can achieve an adjustable dual frequency with omnidirectional radiation patterns. In contrast to the inverted-F antenna (IFA), which is now widely used in handsets, ISA is a kind of micro-strip antennas with a centrally located parasitic element between a folded and feed element, originally developed in the early 1990’s and patented in Australia [1] and USA [2]. In this smart configuration, the folded element connected to the ground line and the feed element connected to the feed produce an adjustable dual frequency and provide omnidirectional radiation patterns at two different frequency bands. Moreover, the element connected to ground determines the lower operating frequency, and the feed element the higher one. In addition, the two operating-frequencies of the antenna are found to have the same polarization plane and broadside radiation patterns. However, as a large number of objectives, decision parameters and considerable parameter tuning work are involved, as well as the field coupling between different elements is required to take into consideration in the synthesis of an ISA, the promising performances of an ISA can only be pursued when some specified robust synthesis methodologies are applied.

A. Mathematical Model

To design an ISA with desirable performances, apart from the minimization of the volume of the antenna, the goals of the optimization are proposed further to include: maximize the bandwidth of S_{11} and minimize the return loss at the two resonant frequencies. Such synthesis problem is a many-objective synthesis, which might result in dramatic deteriorations of the selective pressure when a vector genetic algorithm is employed. Therefore, it would be desirable if the objectives could be reduced without sacrificing the solution quality. In this point of view, the bandwidth and return loss requirements for each resonant frequency are integrated into a new fitness function of the bandwidth of S_{11}. Mathematically, the proposed fitness functions are formulated as:

$$f_j = \sum_{i}^{N}[1+\delta(f_i - f_{cj})][S_{11}(f_i)-10](j=1,2) \qquad (1)$$

where, f_{cj} is a resonant frequency, i.e. 2.4GHz or 5GHz、δ $(f\text{-}f_{cj})$ is the Dirac function, N is the number of sweeping frequency points within 5% bandwidth of the resonant frequency.

By using this new defined fitness function, the fitness assignment mechanism will favour trying on different intermediate solutions when these solutions, other things being equal, have the same bandwidths, which will sustain the necessary diversity of the population in the optimization process.

After introducing the two new fitness functions f_j (j=1,2), the optimal goals of the synthesis of an ISA read as: minimize f_j (j=1,2) and the volume of the antenna.

B. An Improved Vector Optimizer

The Non-dominated Sorting Genetic Algorithm-II (NSGA-II) [3] is extended as the vector optimizer for solving the ISA synthesis in this paper. Since the penalty-parameterless constraint-handling approach of NSGA-II often gives unfeasible geometric parameters for finite element modeling, one introduced and incorporated some geometrical constraints into the optimal model. Moreover, these constraints are transformed into two linear constraints with preconditioned variable bounds, resulting in a simple randomly iterative sampling procedure in the numerical implementation. Finally, thanks to the success in the development of some specific intermediate recombination manipulator as the crossover operator, all the individuals generated are automatically met these linear constraints.

C. Field Computation and the Application of a Response Surface model

To consider the coupling effect of different elements, the finite element method is used to determine the performance parameters of an ISA. However, the heavy computational burdens of a considerable large number of total finite element analysis required by NSGA-II are unaffordable for some engineering applications. In this regard, the multiquadric radial basis function [4] based response surface model is extended and used. It should be pointed out when the number of sampling points employed is within certain limits, a small shape parameter is better in view of constructing the profile of the response surface. However, this will lead to inaccurate numerical results. Moreover, with the increase of sampling points, an ill-conditioned matrix will appear. To alleviate these deficiencies, some regularization technique, or the introduction of smoothness parameter together with a stabilizing function, are proposed. In this regard, Engl's criterion to optimize the smoothness parameter is introduced, resulting in not only a more smoothed response surface, but also an improvement of the condition number for the interpolation matrix.

II. Numerical Example And Conclusion

The proposed numerical techniques are employed to optimize a dual-frequency band inverted-S antenna operating at 2.4 GHz and 5 GHz. In the numerical experiments, the finite element method is used to determine the performance parameter of the antenna.

To start with, 800 sampling points are firstly generated and the performance parameters of these sampling points are determined by means of finite element analysis; and the improved multiquadric radial basis function is then used to reconstruct the optimal problem; finally, the NSGA-II is run on the reconstructed problem to efficiently find the Pareto optimals of the optimal problem. If no proper solutions are searched in the current iterative cycle, some sampling points are added and the aforementioned procedures are repeated until some good solutions are attainable. In the numerical implementation of NSGA-II, the size of population is set to 100, and the number of maximum generations is set to 1000.

The final Pareto solution searched by using the proposed methodology is shown in Fig. 1. To compare performances of the optimized configuration and the original design which is obtained by using a rule of thumb, of the ISA, a solution in the Pareto front as marked in red circle is selected and the details are tabulated in Table I. The corresponding curves for Parameter S_{11} are depicted in Figs.2~3. From these numerical results, it is obvious that the proposed methodology can find a set of best compromising solutions of a many-objective design problem in a single run. Moreover, the performance parameters for the selected specific solution are much better than those of the original design. Therefore, the paper provides not only robust synthesis technique for an ISA design, but also provide more freedoms for a decision maker to select a specific solution from these Pareto solutions according to his/her preferences.

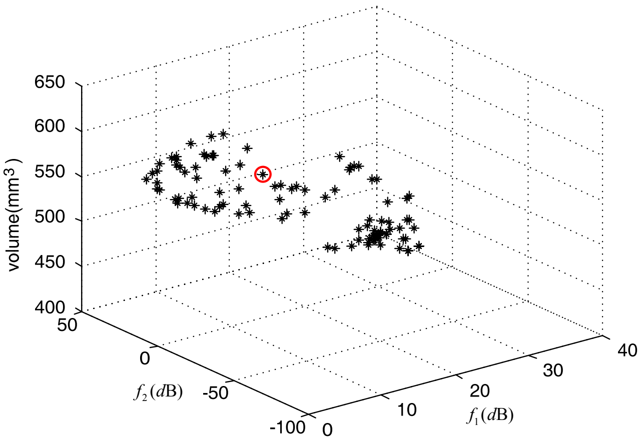

Fig. 1 The searched Pareto solution of the proposed methodology: the red circle is a specified solution highlighted in this paper

TABLE I
Comparison Between The Original And The Optimal Design For A Specific Solution Selected From The Searched Pareto Solutions

	Bandwidth (2.4GHz)	Return loss (2.4GHz)	Bandwidth (5GHz)	Return loss (5GHz)
Original	5.3%	-15dB	10.7%	-20dB
Optimal	6.97%	-33.6dB	14.97%	-34dB

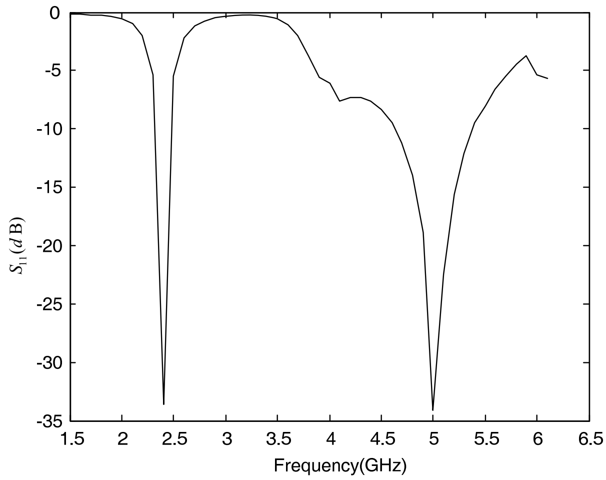

Fig 2. The return loss of the optimized dual frequency ISA.

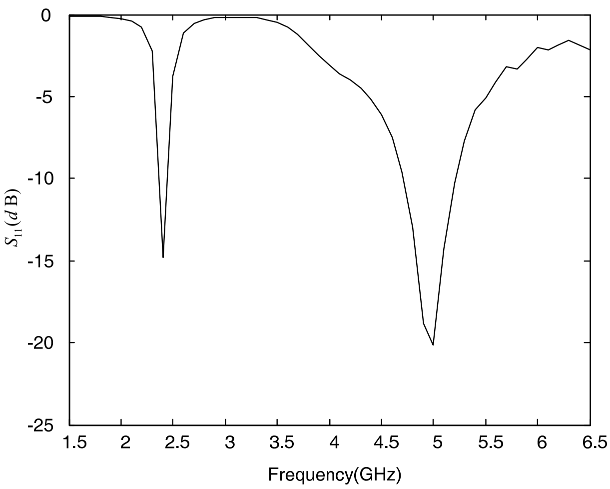

Fig. 3. The return loss of the original dual frequency ISA.

III. Acknowledgment

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IV. References

[1] D. Thiel, J. Lu and S. O'Keefe: Antennas for Use in Portable Communication Devices, PCT Specification 679992, *Australian Patent*, 1995.

[2] D. Thiel, S. Okeefe and J. Lu: Directional Antennas, *USA Patent # 62886 B1*, 2001.

[3] Deb, K., Pratap, A., Agarwal, S., Meyarivan, T.,"A fast and elitist multiobjective genetic algorithm:NSGA-II," *IEEE Transactions on Evolutionary Computation*, vol.6, pp. 182 – 197, 2002.

[4] Hardy R., "Multiquadric Equations of Topography and other Irregular Surfaces," *Journal of Geophysical Research*, vol. 76, pp. 1905-1915, 1971.