Pareto Optimal Design of Ultra-wideband 3-dB Directional Coupler Using Generalized Differential Evolution Algorithm

Xie Lei[1] and Wei Yuqing*[1]

[1] The 54th Research Institute of China Electronics Technology Group Corporation
Shijiazhuang, Hebei 050081, China
xielei0609@163.com
weiyuqing86@126.com

Abstract

Broadband microwave directional couplers are a very important category of passive microwave circuits. A novel method for the design of the tapering shape of broadside-coupled directional couplers is presented. The design method is based on generalized differential evolution (GDE3), which is a multi-objective extension of differential evolution. Three objectives are considered in this design: the return loss, coupling and isolation. The achieved Pareto front presents optimal possible trade-offs among the three objectives. The results indicate the advantages of this approach and the applicability of this design method.

1. Introduction

Directional couplers are very important passive microwave devices, which are widely used in balanced mixers, modulators, and beam forming networks. It has been demonstrated that the broadside coupling approach can lead to the design of a fine quality 3-dB directional coupler operating over an UWB band. In [1], Amin M. Abbosh employed a theoretical model to investigate effect of the tapering shape on performance of the broadside-coupled directional coupler. It is shown that the tapering shape has a significant effect on the coupler's performance. However, in their study the tapering shape is modeled by a general exponential equation and the design freedom is limited.

In this paper, the GDE3 algorithm is applied to the design and optimization of broadside-coupled directional couplers operating in the 3.1-10.6GHz band. In our approach, the tapering shape is modeled by means of a spline curve and by using a set of "control points" the design freedom is improved significantly. We consider three objective functions subject to specific constraints: the return loss, coupling and isolation. Three design cases of the resultant Pareto fronts are compared and discussed. One of the advantages of our approach is that the optimal tapering shapes subject to each objective can be obtained automatically and simultaneously.

2. Directional Coupler Design Using GDE3

GDE3 that introduced in [2] can solve problems that have an arbitrary number of objectives and constraint functions. GDE3 has outperformed other evolutionary algorithms in numerical benchmark problems [3, 4]. It has also been successfully applied to optimization problems in engineering electromagnetics [5].

Configuration of the multilayer broadside coupled directional coupler is shown in Figure 1. The coupler consists of three conductor layers interleaved by two dielectrics. In the present design a substrate with the thickness of 0.508mm and the dielectric constant of 3.38 is selected for the coupler. The top conductor layer includes ports 1 and 3. The bottom conductor layer is similar to the top layer, but the ports here are ports 2 and 4. This work is aimed to investigate effect of the tapering shape on performance of the directional coupler by using GDE3. Figure 2 shows the representative parameters of the tapering shape. Since a symmetry condition, only a quarter of the physical structure is modeled and therefore the geometry turns out to be completely characterized by the following array of geometric variables

$$\overrightarrow{X} = \{(x_i, y_i),\ i = 1, 2, ..., 7\}. \tag{1}$$

To reduce the number of optimization variables we always have

$$x_2 = x_5;\ x_3 = x_6;\ x_4 = x_7 = 0. \tag{2}$$

Then the nine variables to be optimized are

$$\overrightarrow{X}_{opt} = \{\mathrm{y}_i,\ i = 2, 3, ..., 7;\ x_1,\ x_2,\ x_3\}. \tag{3}$$

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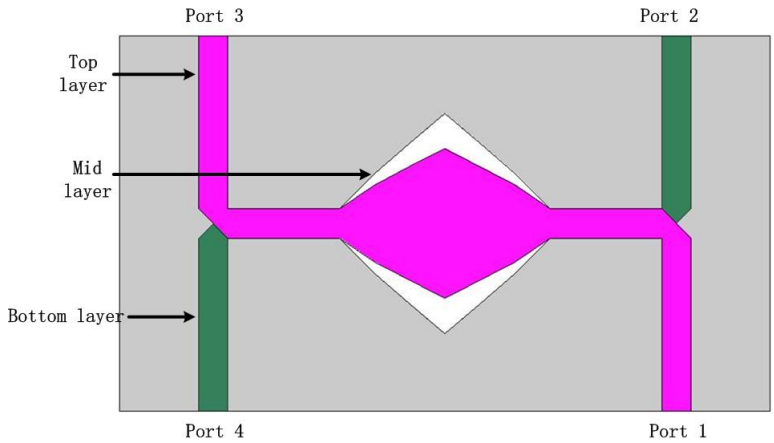

Figure 1 Configuration of the multilayer broadside-coupled directional coupler.

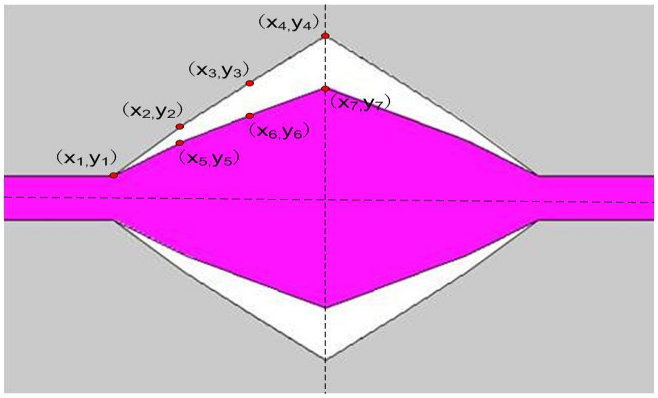

Figure 2 The representative parameters of the tapering shape.

The 3-dB directional coupler design goal is to found the optimum geometry that satisfies given performance specifications such as high isolation, low return loss, and small coupling factor derivation. It is obvious that such a problem is multi-objective. In this paper we express the design problem as the minimization of the following objective functions:

$$\begin{aligned} f_1 &= \max_{3.1GHz \le f \le 10.6GHz} (S_{11}) \\ f_2 &= \max_{3.1GHz \le f \le 10.6GHz} (S_{14}) \\ f_3 &= \max\left\{ \max_{3.1GHz \le f \le 10.6GHz} (|S_{12} + 3dB|),\ \max_{3.1GHz \le f \le 10.6GHz} (|S_{13} + 3dB|) \right\} \end{aligned} \tag{4}$$

where $|\ \ |$ means getting the absolute value. Moreover, the design problem is subject to the following constraints:

$$\begin{aligned} f_1 &\le -25dB \\ f_2 &\le -25dB \\ f_3 &\le 2dB \end{aligned} \tag{5}$$

The S-parameters are calculated by using IE3D software which is based on method of moment [6]. The control parameters chosen for GDE3 are according to [7] for solving problems with three objectives F = 0.2, CR = 0.2. The population size is set to 50 and the maximum number of generation is 200.

The 3D Pareto front found by GDE3 is given in Figure 3. It is observed that design 1 outperforms other designs in terms of return loss. Design 2 presents the highest isolation while design 3 provides smallest coupling factor derivation of all. The performances of the three cases are reported in Figure 4 and Figure 5 shows the corresponding tapering shapes.

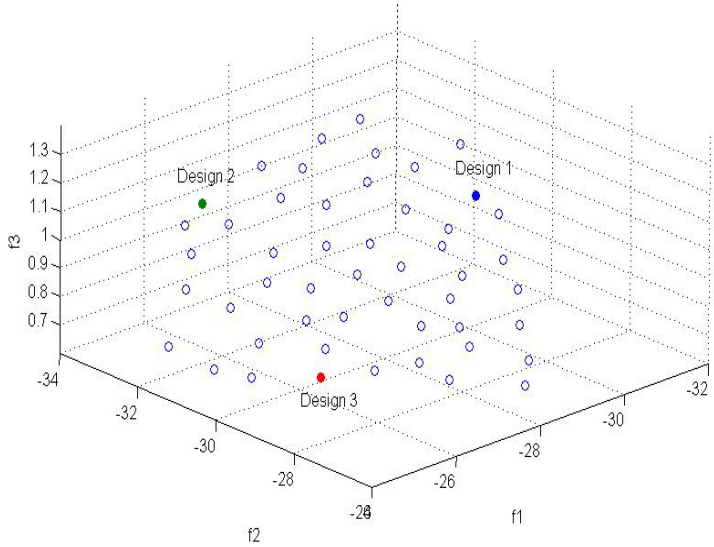

Figure 3 Pareto front found by GDE3 and the three selected cases.

	Return loss	Isolation	Coupling factor
Design 1	≤-30.54dB	≤-30.64dB	-3±0.93dB
Design 2	≤-26.23dB	≤-33.45dB	-3±1.04dB
Design 3	≤-26.15dB	≤-29.58dB	-3±0.68dB

Figure 4 The performances of the three selected cases.

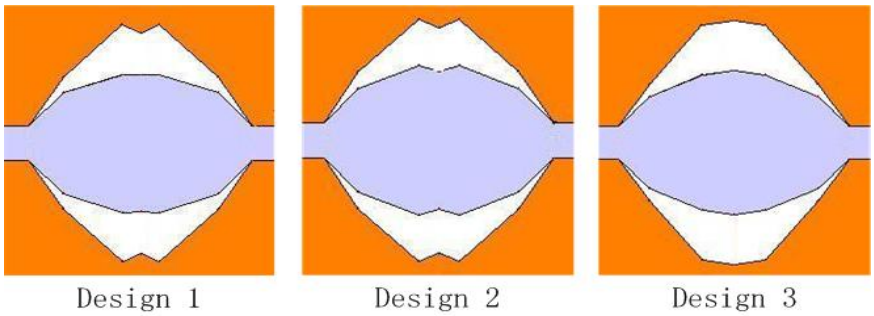

Figure 5 The tapering shapes of the three selected cases.

3. Conclusion

The GDE3 algorithm has been used to study effect of the tapering shape on performance of the broadside-coupled directional coupler. GDE3 can provide the optimum trade-off among the three objectives in a 3D Pareto front. And it shows that the most suitable tapering shapes subject to each objective is different from each other.

4. References

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