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On the Design and Optimization of Waveguides Using Evolutionary Approaches

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Abstract—**This paper presents a new and efficient CAD-oriented algorithm for the design and optimization of high frequency coupled coplanar waveguides (CCPW's). The technique is based on genetic algorithms to obtain the global optimal solution of the problem. The proposed algorithm optimizes a multi-objective, highly non-linear problem having multiple local minima with one constraint. The new approach obtains the optimal structure dimensions that minimize the attenuation and at the same time be as close as possible to the circuit matching condition. After validation, the proposed technique is compared to a global search optimizer and then successfully applied to the design of practical monolithic implementations.**

I. Introduction

Coupled coplanar waveguides (CCPW's) have applications in several components for hybrid and monolithic microwave integrated circuits (MMIC's) [1]-[3]. It is thus conceivable that the design of CCPW's should involve efficient CAD-oriented algorithms and tools that accurately obtain the optimal waveguide dimensions based on certain objectives. On the other hand, genetic algorithms (GAs) are numerical optimization techniques inspired by both natural selection and natural genetics, which are unconditionally stable. The method is a general one, capable of being applied to an extremely wide range of problems. GAs have proven themselves for optimizing many large and complex problems in our field [4]-[5].

Some optimization problems have multiple local minima/maxima, in which gradient-based methods become trapped in one of these local extremes, resulting in a non-optimal solution. On the other hand, GA is a branch of what used to be called heuristic search techniques that differed based on their search algorithms. GA's are found efficient in finding the global solution for problems having multiple local extremes [6]. In this case, genetic-based algorithms should outperform standard methods because standard optimization techniques are suitable only for well-posed problems and problems with no more than one local extreme.

From the above, it is useful to explore GAs for practical design problems. There are two main goals of this paper. First, is to lay the foundation for a genetic algorithm capable of optimizing real-valued problems. Second, is to apply this GA to a practical design problem. In this paper, a genetic algorithm is applied to the design of a coupled coplanar waveguide structure aiming to minimize the attenuation while satisfying the circuit matching conditions. The model for the attenuation and characteristic impedance are based on the formulas provided in [7]. The cross-section of the CCPW is shown in Fig. 1. It is worth underlining the fact that the proposed algorithm is both general and versatile and that it can be applied to any problem. To demonstrate its advantages, it will be applied here to a practical design example of a CCPW.

II. Problem Formulation

A generic flow chart of the proposed algorithm is given in Fig. 2. The approach presented in this paper is based on the implementation presented in [4]. However, a different objective function and

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constraints suitable for the new problem provided in this paper have to be developed. The objective function that needs to be minimized is given by Eq. (1).

$$Objective = F = \min\left\{abs(Z_c - 50) + \alpha_c\right\} \tag{1}$$

In the above equation, Z_c and α_c are the odd- or even-mode characteristic impedance and attenuation constant, respectively. The objective of the above equation is to have a characteristic impedance as close as possible to 50 Ω (for circuit matching issues) and minimize the attenuation at the same time. Clearly, the two components in (1) have different weights that can be implemented in several ways. The equations for the attenuation constant and characteristic impedance are provided by [7].

III. Technique Validation

In this section, the proposed technique is used to optimize the objective function given by:

$$F = \min\left\{w_1 * abs(Z_c - 50) + w_2 * abs(\alpha_c - 0.5)\right\} \tag{2}$$

The aim of (2) is to find the structure dimensions for a characteristic impedance and attenuation as close as possible to 50 Ω and 0.5 N_p/meter, respectively. The weights, w_1 and w_2 are penalty parameters used in the code for a faster convergence. The values of w_1 and w_2 used in the simulations are 0.1 and 10, respectively. Figs. 3-4 give the simulation results for the attenuation and characteristic impedance, respectively. The optimal dimensions a, b, and c found by the proposed technique are 333.51, 692.23, and 1161.82 μm. It is noteworthy to indicate that the results in Figs. 3-4 are obtained concurrently by the proposed simulator. The results provided in this paper are for a frequency of 5.0 GHz, strip thickness t of 5.0 μm, and strip conductivity ρ of $5.8\text{x}10^7$ S/m. The effective dielectric constant is estimated as the average of air and substrate. The substrate is assumed to be GaAs with relative permittivity of 12.9.

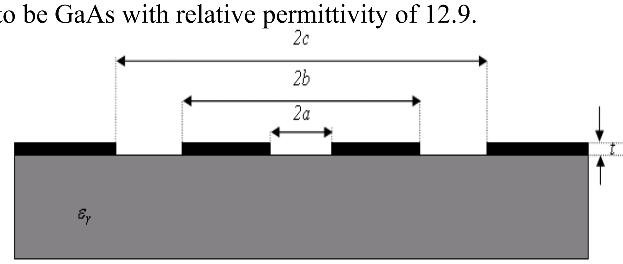

Fig. 1. Cross section of a two-conductor symmetrical CCPW on a semi-infinite dielectric substrate. The strip width is $b-a$, the central slot width is $2a$, and the lateral slot width is $c-b$.

Table I
Comparison Between the Proposed Algorithm and "DIRECT" Algorithm for Different Cases/Objectives

Objectives	††$F^D_{min.}$ *(DIRECT)*	$F^{GA}_{min.}$ *(This Work)*	*Optimal Dimensions Obtained by GA* (μm)		
			a	*b*	*c*
$Z_c = 40\Omega$ *and* $\alpha = 0.5\, N_p / meter$	0.4068	0.0437	229	786	1125
$Z_c = 50\Omega$ *and* $\alpha = 0.5\, N_p / meter$	0.1388	0.0000956	333	692	1161
$Z_c = 60\Omega$ *and* $\alpha = 0.5\, N_p / meter$	0.3516	0.0002083	501	784	1361
$Z_c = 70\Omega$ *and* $\alpha = 0.5\, N_p / meter$	0.6588	0.16357	677	909	1741

†† DIRECT[8] algorithm searches for the optimal solution within a given domain. Since the domain in which the optimal solution exists is not known apriori, the results in Table (I) are obtained by providing an arbitrary domain for DIRECT to search within.

TABLE II

Design of CCPW's Using the Proposed Algorithm Based On Eq. (1)

Objectives	F	$Z_c(\Omega)$	% *error in* Z_c	$\alpha_{min.}(N_p/m)$	*Optimal Dimensions* (μm)		
					a	b	c
$Z_c = 40\Omega$ *and* $\alpha_{min.}$	1.40	40.001	0.00355	1.404	71	252	374
$Z_c = 50\Omega$ *and* $\alpha_{min.}$	1.64	49.996	0.00664	1.644	91	189	321
$Z_c = 60\Omega$ *and* $\alpha_{min.}$	1.88	59.999	0.000766	1.885	113	179	329
$Z_c = 70\Omega$ *and* $\alpha_{min.}$	2.15	70.000	0.00002857	2.154	140	188	357

IV. DESIGN OF CCPW'S AND DISCUSSIONS

The GA algorithm presented in this paper is compared with the DIRECT optimization algorithm, which was first introduced by [8]. It was created to solve difficult global optimization problems with constraints and a real-valued objective function. The code used for DIRECT was taken from Ref. [9]. Table I shows the comparison results. One concludes that the proposed algorithm achieves much better results. The reason is that the proposed algorithm searches the whole space for the optimal solution, in which the DIRECT algorithm requires the user to provide a domain to search within. The optimal CCPW dimensions obtained by the proposed algorithm are given in Table I. The proposed technique is then used to design different CCPW structures that minimize the attenuation, while having specific matching conditions. Table II shows the simulation results. It is worth mentioning that in the simulation, the dimension c has a constraint to be less than 400 μm, i.e., corresponding to practical monolithic implementations. For instance, to have a characteristic impedance as close as possible to 50Ω, while attenuation is minimized, the dimensions a, b, and c should be 91.23, 189.97, and 321.33 μm. For this specific case, the minimum attenuation is found by the proposed approach to be 1.644 N_p/meter.

V. CONCLUSION

We present an efficient CAD-oriented real-coded GA for the design and optimization of coupled coplanar waveguides. The proposed approach obtains the optimal CCPW structure dimensions that satisfy specific requirements, which is considered a new application for genetic algorithms. Two design parameters are considered, namely attenuation and characteristic impedance. Results show that the proposed approach outperforms a standard global search optimizer. In addition, successful design of practical monolithic implementation were provided. Work is being done now to apply the developed GA for the design of high-frequency inductors.

ACKNOWLEDGEMENT

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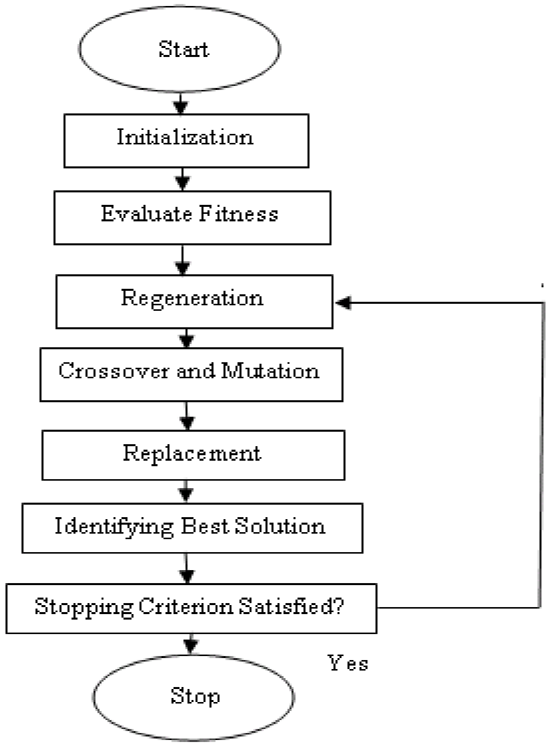

Fig. 2. Generic flow chart of the proposed genetic algorithm.

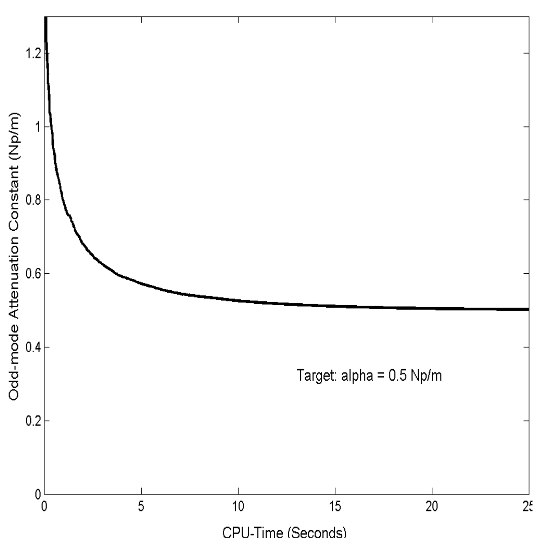

Fig. 3. Convergence curve for the odd-mode attenuation versus CPU-time

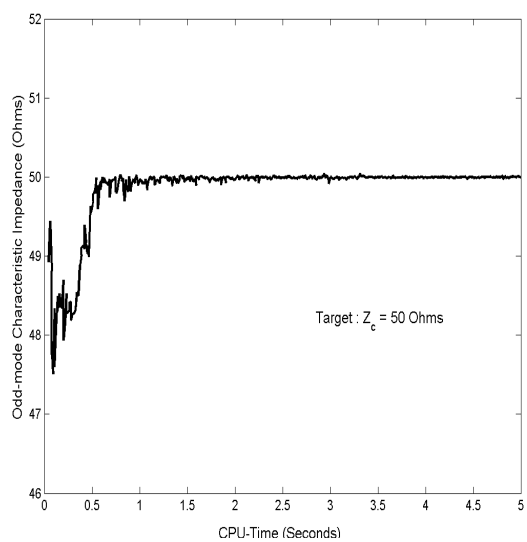

Fig. 4. Convergence curve for the odd-mode characteristic impedance versus CPU-time.