Extraction of Equivalent Circuits for Microstrip Components and Discontinuities Using the Genetic Algorithm

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***Abstract*—This letter introduces a new technique based on the application of the genetic algorithm (GA) for extracting the equivalent circuits—from measured or computed S-parameters—that can be inserted into SPICE simulations. The GA is a robust optimization tool that is shown to yield excellent results for discontinuities in microstrip lines, for instance a right-angled bend, and for microwave circuits, e.g., planar inductors and parallel plate capacitors.**

***Index Terms*—Genetic algorithms, microstrip components, microstrip discontinuities, S-parameters.**

I. Introduction

THIS LETTER is concerned with the problem of extracting the equivalent circuit of a discontinuity, e.g., a bend or a via in a microstrip line, or that of a microwave component, for instance, a planar inductor or a parallel plate capacitor. Typically, field solvers and measurement systems, such as network analyzers, generate S-parameter representations of these discontinuities and components. However, circuit simulators, e.g., SPICE, require conventional equivalent circuits with lumped parameters that can be conveniently inserted into the simulation program. In view of this, a technique for extracting the equivalent circuit, as well as its component values, from a given S-parameter representation is highly desirable. The objective of this paper is to present an optimization technique, called the genetic algorithm (GA) [1]–[4], to address the above problem.

The equivalent circuits of a right-angled bend, a planar inductor, and a parallel plate capacitor are shown in Figs. 1, 3, and 5, respectively [5]–[7], together with their physical configurations. In this work, the component values of the above equivalent circuits are regarded as the parameters to be optimized by the GA.

II. Derivation of Equivalent Circuits Using the GA-Case Examples

In this section we demonstrate the usefulness of the GA by presenting three case examples mentioned in Section I.

Case Example 1: In the first example, we consider the problem of a right-angled bend in a microstrip line, whose geometry and the known equivalent circuit derived from Gupta [5], is shown in Fig. 1. We demonstrate that the GA can recover the correct equivalent circuit component values of the discontinuity. We begin with a set of S-parameters that was calculated for the right-angled bend by a commercially available software Ensemble, for the frequency range of 1–10 GHz. The GA views the S-parameter information as

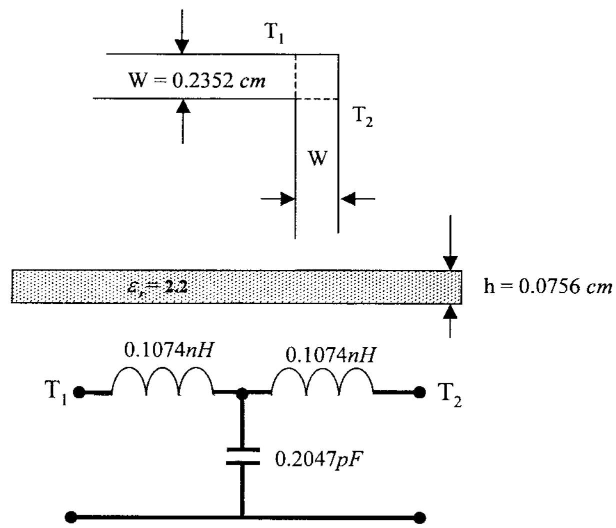

Fig. 1. Right-angled bend in microstrip line and its equivalent circuit.

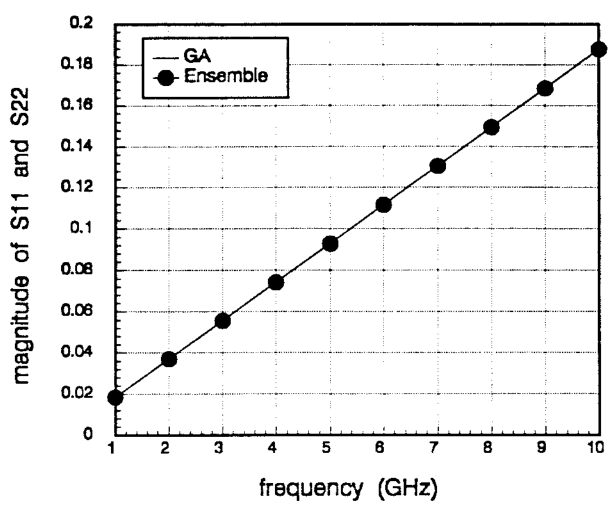

Fig. 2. Magnitude of the specified S_{11} and S_{22} and those derived from the GA for a right-angled bend.

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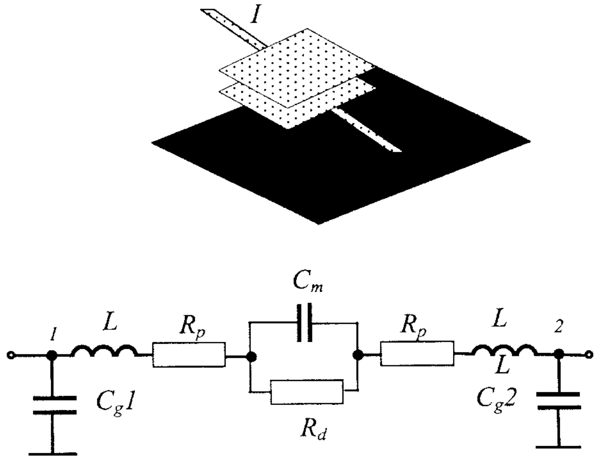

Fig. 3. Physical configuration of a parallel plate capacitor and its equivalent circuit.

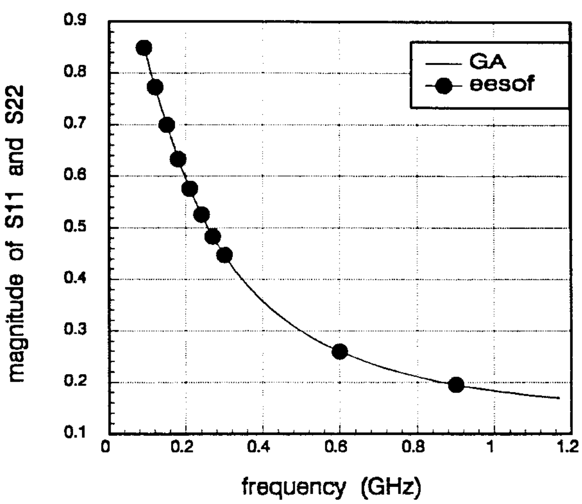

Fig. 4. Comparison of the specified $|S_{11}|$ and $|S_{22}|$ of the parallel plate capacitor with those computed from the equivalent circuit selected by the GA.

the specifications and searches for the component values of the equivalent circuit that meets these specifications. In the optimization process, the GA starts from a large population of randomly selected circuit component values and guides the population toward better solutions through repetitive applications of reproduction, crossover, and mutation operators.

While applying the GA in the optimization process, each of the component values of the circuit is specified by using 10 bits. The objective function which is minimized to determine the circuit parameters, is chosen to be

$$F = \sum_{n=1}^{N_f} \sum_{i=1}^{2} \sum_{j=1}^{2} \mid S_{ij}(f) - S_{ij}^{\mathrm{GA}}(f) \mid^2 \qquad (1)$$

where

- N_f total number of frequencies of interest;
- S_{ij} specified S-parameters of the right-angle bend;
- S_{ij}^{GA} S-parameters calculated from the equivalent circuit selected by the GA.

Though not shown here, the final component values of the GA-optimized equivalent circuit were identical to the ones given in Fig. 1, up to four decimal points. As a consequence, the S-parameters computed for the GA-derived circuit duplicate the ones calculated by Ensemble almost exactly (see Fig. 2).

Case Example 2: In the following we further illustrate the application of the GA technique to the problem of deriving the equivalent circuits of microwave components. The first example we consider in this category is that of a parallel plate capacitor whose physical configuration and equivalent circuit (obtained from [6]) are shown in Fig. 3. The component values of the circuit are listed in Table I. The set of specified S-parameter for the given circuit in Fig. 3 was computed via EESOF. The component values chosen by the GA for the given equivalent circuit of the parallel plate capacitor are also shown in Table I. The S-parameters of the circuit chosen by the GA were identical to the ones computed by the EESOF up to three decimal points. Fig. 4 plots the magnitude of the specified S_{11} and S_{22}, and compares them with those computed from the equivalent circuit whose component values were selected by the GA. It is evident from the plot that the GA-derived circuit yields excellent results for the S-parameters of the parallel plate capacitor. However, we also note that there appears to be considerable differences between some of the component values chosen by the GA and those used to derive the specified S-parameter. This implies that the S-parameter results are relatively insensitive to these component values of the equivalent circuit, at least in the frequency range of interest. We have verified this assertion by perturbing these component values from those determined by the GA and have found that the S-parameters change relatively little.

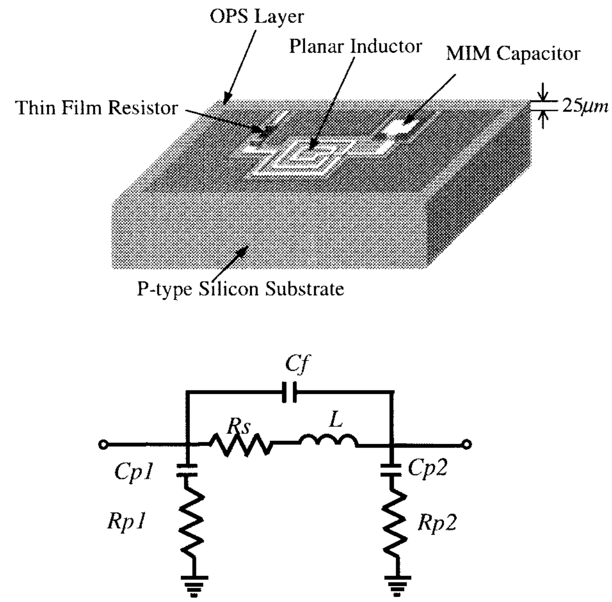

Fig. 5. Physical configuration of a planar inductor and its equivalent circuit.

Case Example 3: In this last example we consider the problem of determining the component values of the equivalent circuit of a planar inductor from its S-parameters. EESOF was used to determine the specified S-parameters of the equivalent circuit. A fabricated inductor on the oxidized porous silicon (OPS) and its equivalent circuit (obtained from [7]) are

TABLE I
COMPARISON OF ORIGINAL AND GA-DERIVED COMPONENT VALUES FOR THE PARALLEL PLATE CAPACITOR SHOWN IN FIG. 3

Component values of the equivalent circuit	Component values chosen by the GA
$C_{g1} = C_{g2} = 0.2798\ pF$	$C_{g1} = C_{g2} = 0.3770\ pF$
$L = 0.3847\ nH$	$L = 0.6387\ nH$
$R_p = 0.0189\ \Omega$	$R_p = 0.0195\ \Omega$
$R_d = 29288.8986\ \Omega$	$R_d = 29284.05\ \Omega$
$C_m = 10.8679\ pF$	$C_m = 10.8398\ pF$

TABLE II
COMPARISON OF ORIGINAL AND GA-DERIVED COMPONENT VALUES FOR THE PLANAR INDUCTOR SHOWN IN FIG. 5

Component values of the equivalent circuit	Component values chosen by the GA
$R_{p1} = 218\ \Omega$	$R_{p1} = 215.63\ \Omega$
$R_{p2} = 137\ \Omega$	$R_{p2} = 138.28\ \Omega$
$R_s = 9.83\ \Omega$	$R_s = 10.39\ \Omega$
$C_{p1} = 19.4\ pF$	$C_{p1} = 20.02\ pF$
$C_{p2} = 25.8\ pF$	$C_{p2} = 47.75\ pF$
$C_f = 3.67\ pF$	$C_f = 3.59\ pF$
$L = 6.29\ nH$	$L = 6.48\ nH$

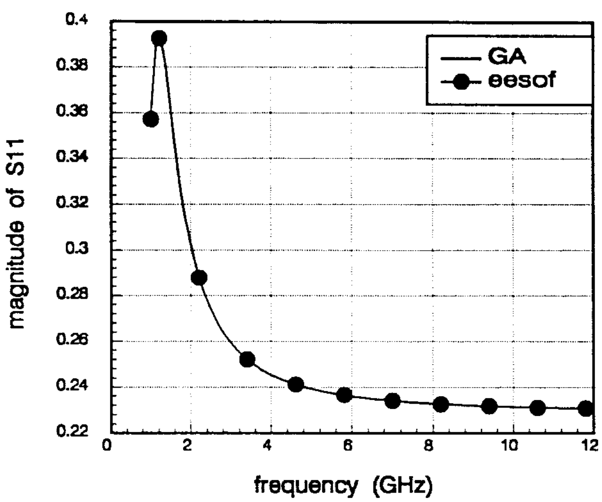

Fig. 6. Comparison of the specified $|S_{11}|$ of the planar inductor with that computed from the equivalent circuit selected by the GA.

depicted in Fig. 5. The component values used to determine the specified S-parameters and the component values selected by the GA are shown in Table II. We note that once again that some of the component values chosen by the GA are slightly different from those used to compute the original S-parameters via EESOF. However, Fig. 6 clearly demonstrates that the two S_{11} results agree extremely well. Though not shown here, the same is found to be true for other S-parameters as well.

III. CONCLUSIONS

A new technique for extracting the equivalent circuit of a microstrip discontinuity—from its computed or measured S-parameters—has been developed in this letter. The technique is based on the use of the genetic algorithm, which is employed to determine the components of the equivalent circuit via an optimization procedure. Three examples have been presented to validate the approach and to illustrate its versatility.

REFERENCES

[1] R. L. Haupt and S. E. Haupt, *Practical Genetic Algorithms.* New York: Wiley, 1997.
[2] F. Ares, S. R. Rengarajan, E. Villanueva, E. Skochinski, and E. Moreno, "Application of genetic algorithms and simulated annealing technique in optimizing the aperture distributions of antenna array patterns," *Electron. Lett.,* vol. 32, no. 3, pp. 148–149, 1996.
[3] A. Boag, E. Michielssen, and R. Mittra, "Design of electrically loaded wire antennas using genetic algorithms," *IEEE Trans. Antennas Propagat.,* vol. 44, pp. 687–695, May 1996.
[4] D. S. Weile and E. Michielssen, "Genetic algorithm optimization applied to electromagnetics: A review," *IEEE Trans. Antennas Propagat.,* vol. 45, pp. 343–353, Mar. 1997.
[5] K. C. Gupta, R. Garg, and R. Chadha, *Computer-Aided Design of Microwave Circuits.* Norwood, MA: Artech House, 1981.
[6] K.-H. Drue, J. Muller, and K. Thust, "RF models of passive LTCC-components in the lower gigahertz-range," *Advancing Microelectronics,* pp. 23–26, May/June, 1997.
[7] C.-M. Nam and Y.-S. Kwon, "High-performance planar inductor on thick oxidized porous silicon (OPS) substrate," *IEEE Microwave Guided Wave Lett.,* vol. 7, Aug. 1997.