APPLICATION OF GENETIC ALGORITHMS TO THE SYNTHESIS OF TRANSMISSION LINES FOR MONOLITHIC MICROWAVE INTEGRATED CIRCUITS

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ABSTRACT

In this work, continuous parameter genetic algorithm (CPGA) and binary genetic algoithm (BGA) are applied to the synthesis of some planar transmission line structures such as microstrip, slotline and coplanar wavequide for monolithic microwave integrated circuits (MMICs). The results obtained from each algoritm are compared with each other.

I. INTRODUCTION

MMICs have wide range of applications in microwave communication systems, satellite and radar. MMICs have some advantages such as low cost, high reliability and mass producibility, small size and weight, wide bandwidth performance, circuit design flexibility and chip functionality. Microstrip, coplanar wavequide and slotline are the most common planar transmision structures which are suitable as circuit elements in MMICs [1]. In this work , different types of genetic algorithm such as BGA and CPGA are used for synthesizing of microstrip, coplanar wavequide and slotline. Genetic Algorithms (GAs) are known as global optimization algorithms based on evolution and genetic recombination in nature [2]. Genetic algorithms have extensively been used in microwave and electromagnetics areas [3-10]. While chromosomes are represented by binary numbers in BGA, chromosomes are coded by floating- point numbers in CPGA [11]. The results obtained by CPGA are compared with the results obtained by BGA.

II. BGA AND CPGA

The flowchart of a genetic algorithm (GA) is given in Figure 1. A gene is defined as a binary encoding of the parameter of the error (cost) function to be minimized. A set of genes constitutes a chromosome subject to reproduction, crossover, and mutation processes.

In BGA, the chromosomes are coded by binary numbers. After the error function is evaluated for each chromosome, they are ranked from the lowest to the highest error function value. Unacceptable chromosomes are discarded after ranking.

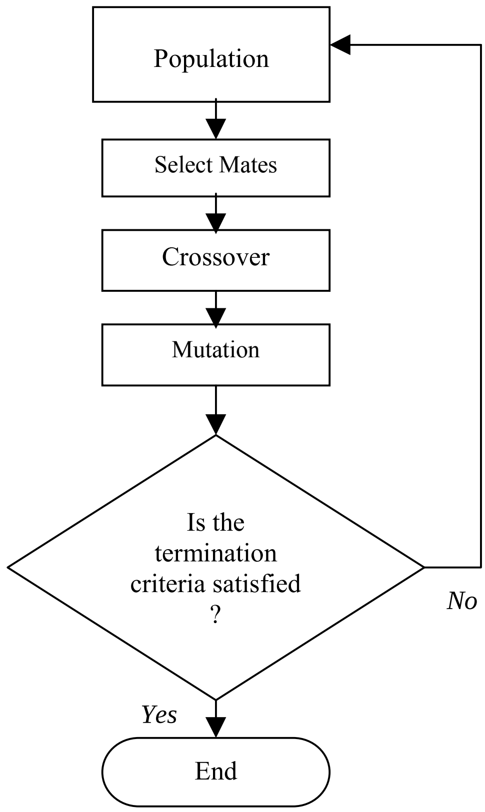


Figure 1. The flowchart of a GA

Next, the crossover operation pairing them at a random crossover point is performed (Figure 2). Mutation process preventing the system from settling into local minima changes a small percentage of the bits in the chromosomes from 1 to 0 or visa versa. Chromosomes are represented by floating- point numbers in CPGA. CPGA has the advantage of accurate representation of the continuous parameters. CPGA requires less storage than the BGA since a parameters in CPGA is represented by a single floating-point number. CPGA also requires less computing-time than the BGA and FGA, since it doesn't need conversion between binary and decimal numbers.

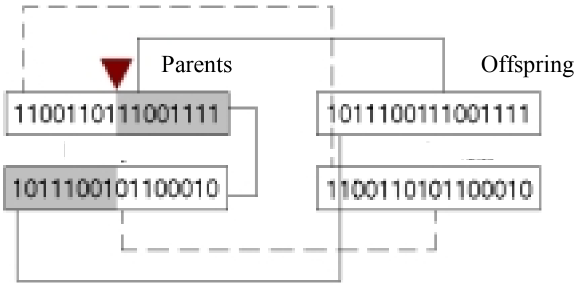


Figure 2. Crossover operation in BGA

The crossover operation for CPGA is represented in Figure 3. The basic method of mutation for CPGA is to replace a mutated parameter by a new random number.

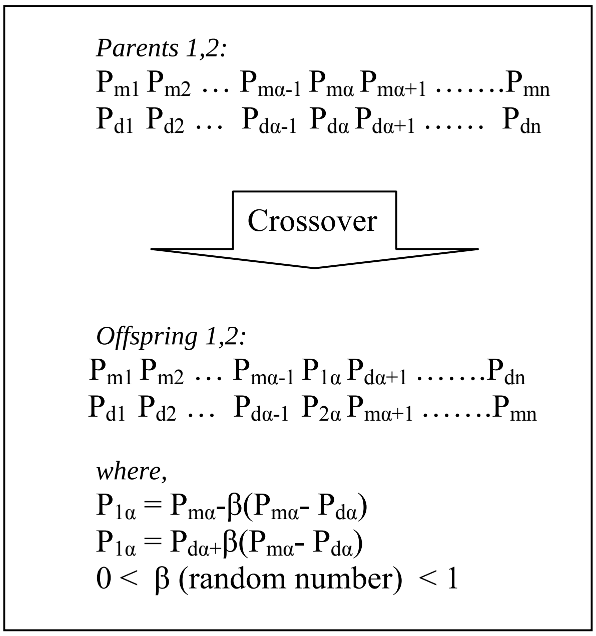


Figure 3. Crossover operation in CPGA

III. SYNTHESIS PROCEDURE

The three basic types of planar transmission line structures are illustrated in Figure 4. The characteristic impedance Z_0 (Ω) of the microstrip line (Figure 4a) are given by [12]

$$Z_0 = \frac{\eta}{2\pi\sqrt{\varepsilon_{re}}} \ln\left(\frac{8h}{W} + 0.25\frac{W}{h}\right) \qquad \left(\frac{W}{h} \le 1\right) \quad (1)$$

$$Z_o = \frac{\eta}{\sqrt{\varepsilon_{re}}} \left\{\frac{W}{h} + 1.393 + 0{,}667\ln\left(\frac{W}{h} + 1.444\right)\right\}^{-1} \qquad \left(\frac{W}{h} \ge 1\right) \quad (2)$$

where

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r + 1}{2} F\left(\frac{W}{h}\right) \quad (3)$$

$$F(W/h) = \begin{cases} (1 + 12h/W)^{-1/2} + 0{,}04(1 - W/h)^2 & (W/h \le 1) \\ (1 + 12h/W)^{-1/2} & (W/h \ge 1) \end{cases} \quad (4)$$

where $\eta = 120\pi$ Ω.

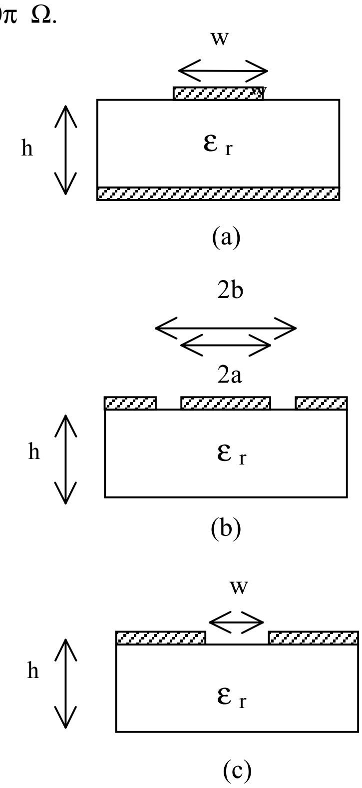


Figure 4. Transmission lines used in MMICs
(a) Microstrip, (b) Coplanar wavequide, (c) Slotline

Design equations for coplanar waveguide (Figure 4b) are given by [1,13,14]

$$Z_0 = \frac{30\pi K(k')}{\sqrt{\varepsilon_{re}}K(k)} \quad (5)$$

$$\varepsilon_{re} = 1 + \frac{\varepsilon - 1}{2} \cdot \frac{K(k')}{K(k)} \cdot \frac{K(k_1)}{K(k_1')} \quad (6)$$

$$k = \frac{a}{b} \quad (7)$$

$$k' = \left(1 - k^2\right)^{1/2} \quad (8)$$

$$k_1 = \sinh\left(k.\pi / 2(h/b)\right) / \sinh\left(\pi / 2(h/b)\right) \quad (9)$$

$$k_1' = \left(1 - k_1^{\,2}\right)^{1/2} \quad (10)$$

$$\frac{K(k)}{K(k')} = \frac{1}{\pi}\ln\left(2\frac{1+\sqrt{k}}{1-\sqrt{k}}\right) \qquad 0.5 \le k^2 \le 1 \quad (11)$$

$$\frac{K(k)}{K(k')} = \pi \Big/ \ln\left(2\frac{1+\sqrt{k'}}{1-\sqrt{k}}\right) \qquad 0 \le k^2 \le 0.5 \quad (12)$$

The design equations for slotline (Figure 4c) are given by [15]

for $0{,}02 \le w/h \le 0{,}2$

$$\begin{aligned} Z_0 = {} & 72.62 - 35.19 \log \varepsilon_r \\ & + 50 \frac{(w/h - 0.02)(w/h - 0.1)}{w/h} \\ & + \log\left(w/h \times 10^2\right)\left[44.28 - 19.58 \log \varepsilon_r\right] \\ & - \left[0.32 \log \varepsilon_r - 0{,}11 + w/h(1.07 \log \varepsilon_r + 1.44)\right] \\ & \cdot \left(11.4 - 6.07 \log \varepsilon_r - h/\lambda_0 \times 10^2\right)^2 \end{aligned} \quad (13)$$

for $0{,}2 \le w/h \le 1{,}0$

$$\begin{aligned} Z_0 = {} & 113.9 - 53.55 \log\varepsilon_r \\ & + 1.25 w/h(114.59 - 51.88 \log\varepsilon_r) \\ & + 20(w/h - 0.2)(1 - w/h) \\ & - \left[0.15 + 0.23 \log\varepsilon_r + w/h(-0.79 + 2.07 \log\varepsilon_r)\right] \\ & \cdot (10.25 - 5 \log\varepsilon_r + w/h(2.1 - 1.42 \log\varepsilon_r) \\ & - h/\lambda_0 \times 10^2)^2 \end{aligned} \quad (14)$$

Equations (13) and (14) have an accuracy of 2 percent in the parameter range $9.7 \le \varepsilon_r \le 20$, $0.02 \le w/h \le 1.0$, $0.01 \le h/\lambda_o \le (h/\lambda_o)_c$

where

$$\left(\frac{h}{\lambda_0}\right)_c = \frac{0.25}{\sqrt{\varepsilon_r - 1}} \quad (15)$$

The error function formed as follows

$$f_{error} = \left|Z_o^d - Z_o^c\right| \quad (16)$$

is minimized by BGA and CPGA. Z_o^d is the desired (given) charactreristic impedance of the transmission line and Z_o^c is the calculated characteristic impedance of the transmission line.

IV. RESULTS

The equations (1)-(4) and (16) are used for synthesizing the microstrip lines. The search interval for the parameter, w/h, is selected as $0.1 \le w/h \le 10$. The parameter is coded by 10 bits in BGA. Total number of chromosomes is chosen as 300. The mutation rate 1 % is applied. The results obtained by BGA and CPGA for microstrip lines are given in Table 1 and the convergence of each algorithm is shown in Figure 5.

Table 1**.** The results obtained by BGA and CPGA for microstrip lines

Z_o^d (Ω)		50	75	100	110
ε_r		2.3	3.8	6.4	8.8
BGA	Z_o^c	49.97	74.979	99.589	109.995
	w/h	3.020	1.015	0.268	0.112
CPGA	Z_o^c	49.99	74.983	99.9458	109.988
	w/h	3.020	1.0159	0.2676	0.113

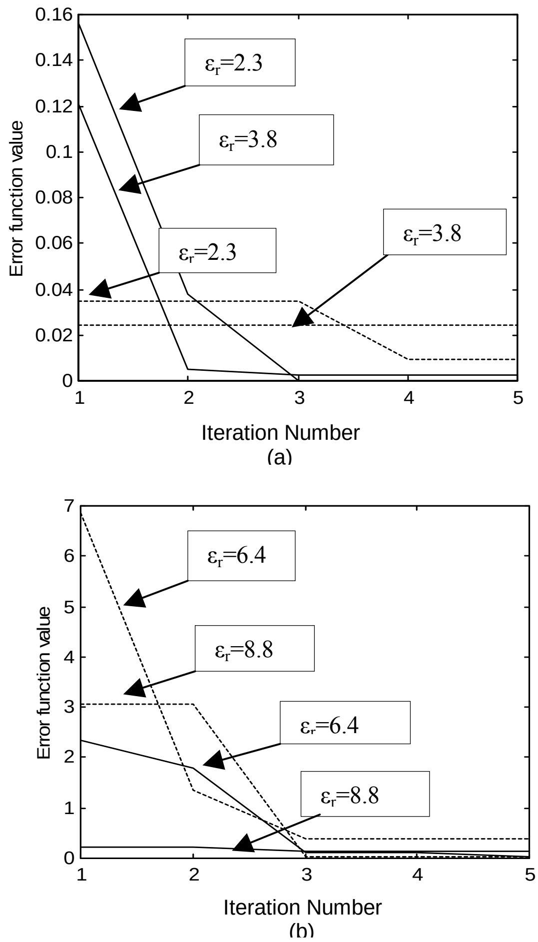


Figure 5. Convergence of the BGA (dashed line) and CPGA (solid line) for the synthesis of microstrip lines (a) for $\varepsilon_r = 2.3$ and 3.8, (b) for $\varepsilon_r = 6.4$ and 8.8

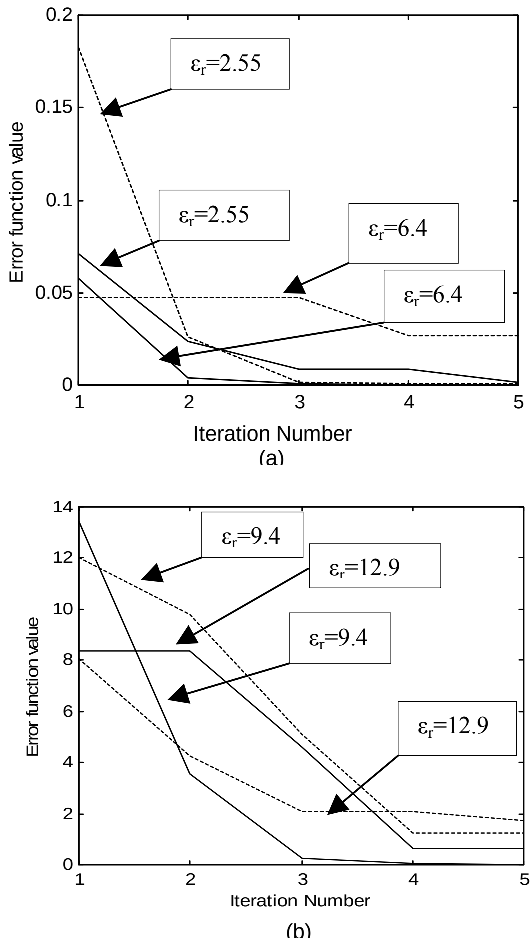


Figure 6. Convergence of the BGA (dashed line) and CPGA (solid line) for the synthesis of coplanar wavequides (a) for $\varepsilon_r = 2.55$ and 6.4, (b) for $\varepsilon_r = 9.4$ and 12.9

The equations (5)-(12) and (16) are used for synthesizing the coplanar wavequides. The search intervals for a/b and h/b are selected as $0.01 \le a/b \le 1$ and $0.1 \le h/b \le 10$ respectively. Each parameter is coded by 10 bits in BGA. Total number of chromosomes is chosen as 300. The mutation rate 1 % is applied. The results obtained by BGA and CPGA for coplanar wavequides are given in Table 2 and the convergence of each algorithm is shown in Figure 6.

Table 2. The results obtained by BGA and CPGA for coplanar waveguides

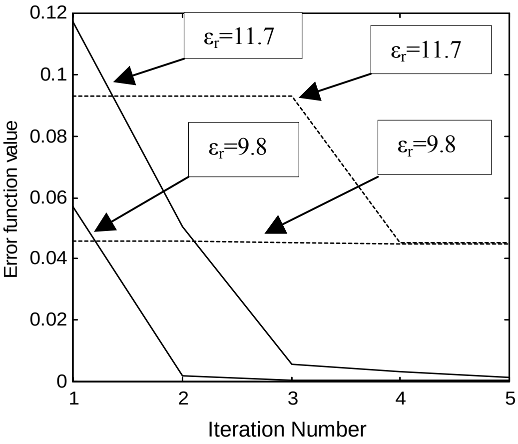
Z_o^d (Ω)		50	50	55	55
ε_r		2.55	6.4	9.4	12.9
BGA	Z_o^c	49.982	49.602	53.284	53.755
	a/b	0.330	0.708	0.708	0.718
	h/b	2.884	1.733	0.264	0.206
CPGA	Z_o^c	49.999	49.999	54.995	54.344
	a/b	0.327	0.727	0.710	0.727
	h/b	7.431	1.056	0.219	0.114

The equations (13)-(16) are used for synthesizing the slotlines. The search intervals for w/h and h/λ_0 are selected as $0.02 \le w/h \le 1$ and $0.01 \le h/\lambda_0 \le (h/\lambda_0)_c$ respectively. Each parameter is coded by 10 bits in BGA. Total number of chromosomes is chosen as 300. The mutation rate 1 % is applied.

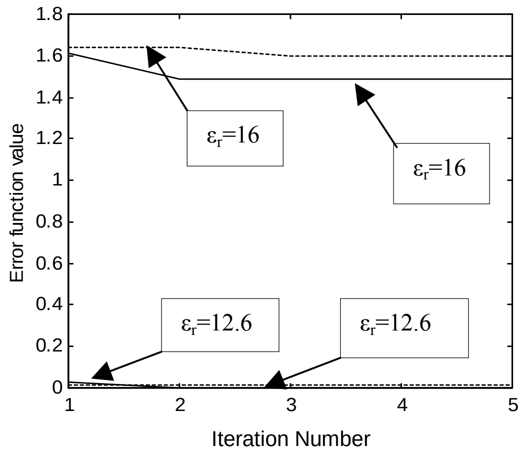
Table 3. The results obtained by BGA and CPGA for slotlines

Z_o^d (Ω)		60	60	70	70
ε_r		9.8	11.7	12.6	16
BGA	Z_o^c	59.955	59.96	69.80	68.40
	W/h	0.243	0.337	0.730	0.992
	h/λ_0	0.102	0.105	0.100	0.105
CPGA	Z_o^c	59.999	59.99	69.99	68.50
	W/h	0.252	0.338	0.717	0.992
	h/λ_0	0.017	0.011	0.019	0.079

The results obtained by BGA and CPGA for slotlines are given in Table 3 and the convergence of each algorithm is shown in Figure 7.



(a)



(b)

Figure 7. Convergence of the BGA (dashed line) and CPGA (solid line) for the synthesis of slotlines (a) for $\varepsilon_r = 9.8$ and 11.7, (b) for $\varepsilon_r = 12.6$ and 16

V. CONCLUSION

BGA and CPGA are applied to the problem of synthesising transmission line structures for MMICs. Simple and accurate formulas in the literature are used in the synthesis procedure. The obtained results show that GA is a suitable synthesis approach for various types of microwave transmission lines. It is also seen that CPGA gives more accurate results than BGA. The computation time requirement for BGA is approximately three times longer than that of CPGA for the synthesis procedure of the transmission lines.

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