Optimum Design of Continuous Microstrip Tapers using Genetic Algorithms

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Abstract

This paper describes an optimum design of continuous microstrip tapers using genetic algorithms (GA's).

This approach has a few advantages: giving a clearer and simpler representation of the problem. In this method genetic algorithms deal with the reduction of the reflection coefficient pattern for a certain range of frequencies. Three different continuous transmission line tapers are compared here, linear, exponential, and Chebyshev with the genetic algorithms.

Genetic algorithms can obtain very small reflection coefficient within the range of frequency, but on the other hand the characteristics impedance form obtained is difficult in practical.

الخلاصـــــــة

تم في هذا البحث وصف تصميم مثالي لموالفة شريطية مستمرة باستخدام الخوارزميات الجينية يملك هذا البحث عدد من الفوائد منها شفافية وبساطة تمثيل المسالة بالخوارزميات الجينية.

في هذا البحث تتعامل بالخوارزميات الجينية مع تقليل معامل الانعكاس ضمن مدى معين من الترددات. وكذلك مقارنة نتائج هذه الطريقة مع الطرق الثلاث وهي التدريج الخطي والتدريج الآسي والتدريج جيبيشيف.

الخوارزميات الجينية يمكن أن تحصل على معامل الانعكاس قليل جدا ضمن مدى معين من الترددات لكن تعطي شكل ممانعة مميزة .صعب التعامل معه من الناحية العملية.

1. Introduction

The operation of an antenna system over a frequency range is not completely dependent upon the frequency response of the antenna element itself but rather on the frequency characteristics of transmission line-antenna element combination. In practice, the characteristic impedance of the transmission line is usually real whereas that of the antenna element is complex. Also the variation of each as a function of frequency is not the same. Thus efficient coupling-matching networks must be designed which attempt to couple-match the characteristics of the two elements over the desired frequency range [1].

The reflection from continuous tapered lines decreases rapidly with frequency, and are more manageable than those from stepped transformer. Four different continuous transmission line tapers are compared here, the linear, the exponential, the Chebyshev and the genetic algorithms tapers. Although a linear taper is not the optimum one, it is of particular interest in waveguide technique because of its ease of fabrication. The fabrication of a transmission line in microstrip technique is quite easy. Therefore, it does not matter when a microstrip non-uniform taper is of arbitrary shape, is provided it has improved characteristic over that of a linear taper [2].

Past works have been concerned primarily with the reflection of linear and sinusoidally tapered waveguides [3]. Reference [4] shows transmission line continuous taper of improved design. A computer aided design has been carried-out for three methods linear, exponential, and chebyshev tapers [2].

2. Genetic Algorithms

The ever increasing advances in computational power have elevated the antenna engineer’s temptation to search for optimum solutions for complex electromagnetic devices. The typically applied brute force design methodologies are gradually being replaced by the state of-the-art optimization techniques. The ability of using numerical methods to accurately and efficiently characterizing the relative quality of a particular design has excited the EM engineers to apply stochastic global evolutionary optimizers (EO). Among these techniques, genetic algorithm (GA) has attracted much attention [5].

Relying on Darwin’s original thoughts it has been argued that life in this world in all its diverse and amazing forms was evolved by natural selection and adaptation processes controlled by the survivability of the fittest species. With this acceptance has come the temptation that perhaps one might be able to utilize nature’s, “selection and adaptation engine” and apply it to the solution of engineering problems via the applications of the genetic algorithms (GA’s) [5].

The main concern in this paper is to find an appropriate coefficient to obtain the minimum reflection coefficient within range of frequencies. Though there have been many approaches to the problem of designing tapers, genetic algorithms may be used as a simple and flexible alternative to achieve the same objective, which other methods can do, and more importantly, it has unique features to treat some complicated problem, which can not be done by other methods.

Genetic algorithms are search and optimization algorithms which have very wide applications. Algorithm started with a set of solutions (represented by chromosomes) called population. Solutions from one population are taken to form a new population. This is motivated by a hope, that the new population will be better than the old one. Solutions which are selected according to their fitness the more suitable they are the more chances they have to reproduce. This is repeated until some condition is satisfied [6,7].

Conventional GA's with binary coding and binary genetic operation are non-convenient and inefficient for antenna problems to optimize real or complex numbers [6]. This approach avoids coding and directly deals with real weighting vector.

2-1 Construction of Chromosomes

Using genetic algorithms for tapers, reflection coefficient patterns are considered to correspond to living beings and coefficient of polynomial vectors are considered to correspond to chromosomes. Using curve fitting to find the coefficient of polynomial of degree N that fit the data. Conventional genetic algorithms encode the parameters in binary chromosomes and perform binary genetic operation. In this approach, chromosomes are represented directly by real reflection coefficient vector.

$$\mathbf{a} = [\mathbf{a}_1 \mathbf{a}_2 \mathbf{a}_3 \ldots \mathbf{a}_n \ldots \mathbf{a}_N] \quad \text{.......... (1)}$$

where,

a: is a chromosome

a_n: is known as a genetic material in a GA(genes) which represents the coefficient of polynomial.

N: is the length of the chromosome (order of curve fitting).

This simple representation explicitly shows the relation between chromosomes in genetic algorithms and the coefficient of polynomial vectors [7,8].

2-2 Initial Population

For fast convergence of genetic algorithms iteration, the initial population can include approximate reflection coefficient by other simple techniques (linear, exponential, and chebyshev tapers), and coefficient by guess based on experience and/or at random [2,6]. In this method random chromosomes are used.

2-3 Fitness Function

The initial populations are produced, and their fitnesses correspond to maximum reflection coefficient (in the certain range of frequencies) for the selection of suitable chromosome to compete for next generation. The input reflection coefficient pattern of matching section is given by [2,8].

$$\rho = \tfrac{1}{2}\int_{-\ell/2}^{\ell/2} \frac{d\left(\ln\left(Z_o(x)\right)\right)}{dx} e^{-j2\beta x} dx \quad \text{...} \quad (2)$$

$$Z_o(x) = a_o + a_1 x + a_2 x^2 + \dots + a_N x^N = \sum_{n=0}^{N} a_n x^n \quad \text{.......................................} \quad (3)$$

where,

ρ: is reflection coefficient

$\beta = {2\pi}/{\lambda}$ =wave number.

λ: is the wavelength.

ℓ : is the length of taper

To solve equation (2), substitute equation (3) in equation (2) and take the derivative for natural logarithmic of $Z_o(x)$ yield:

$$\rho = \tfrac{1}{2}\int_{-\ell/2}^{\ell/2} \frac{\sum_{n=0}^{N-1} a_n n x^{n-1}}{\sum_{n=0}^{N-1} a_n x^n} e^{-j2\beta x} dx \quad \text{...} \quad (4)$$

let N=10 (ninth-order polynomial),and equation (3) becomes:

$$Z_o(x) = a_o + a_1 x + a_2 x^2 + a_3 x^3 + \dots + a_9 x^9 \quad \text{...} \quad (5)$$

substitute equation (5) in equation (4) yield:

$$\rho = \tfrac{1}{2}\int_{-\ell/2}^{\ell/2} \frac{a_1 + a_1 x + 2a_2 x + 3a_3 x^2 + \dots + 9a_9 x^8}{a_o + a_1 x + a_2 x^2 + a_3 x^3 + \dots + a_9 x^9} e^{-j2\beta x} dx \quad \text{..............................} \quad (6)$$

Above equation can be solved using numerical integration (using trapezoidal rule of integration) [8].

Maximum reflection coefficient (ρ_m) through range of frequencies is computed from reflection coefficient pattern.

The objective function is obtained as:

$$\text{error} = \left|\rho_{m\,desired} - \rho_{m\,obtained}\right| \quad \text{.. ....} \quad (7)$$

then:

The fitness function=1/error .... (8)

where: the objective function is the calculation of its associated fitness.

The fitness function is a measure of the quality of a chromosome [9]. When error becomes zero, this mean $\rho_{m desired} = \rho_{m obtained}$ and the program is stopped, and the last chromosome is obtained represents this case.

2-4 Selection

There are many mating techniques available to pick two parent chromosomes to produce child chromosome. These methods are Roulette Wheel selection and Rank selection (6). In this approach Roulette Wheel selection is used.

2-5 Crossover

Crossover is another process that involves exchange of genetic materials between two parent chromosomes to make child chromosome. The simplest way how to do this is to choose randomly some crossover point and then everything before this point copies from the first parent and then everything after a crossover point copies from the second parent. There are many types of crossover: single point crossover, two point's crossover, uniform crossover, and arithmetic crossover (linear crossover) [6]. In this approach a single point crossover is used and crossover probability is equal to 85%.

2-6 Mutation

After a crossover is performed, mutation takes place. This is to parent falling all solutions in population into a local optimum of solved problem. Mutation changes randomly the new offspring (children). There are many types of accomplishing mutation (binary mutation, and real mutation). Real mutation is used according to the following equation, as [10,11]:

$$a_i' = \begin{cases} r(L_o, U_p) & \text{if} \quad z' \le P_m \\ a_i & \text{otherwise} \end{cases} \quad \text{.. (9)}$$

where:

z': is random number.

r (L_o,U_p): is random number with limited range (L_o,U_p).

a_i: is the value of gene before mutation.

a_i': is the value of gene after mutation.

P_m: is probability of mutation equal to (0.5%-1%), in this paper the probability of mutation is equal to 0.5%.

2-7 Stopping Criteria

The progress of reproduction continues until a satisfied result is obtained or preset maximum number of iteration is reached [6]. In this paper 20 iteration is used. **Figure (1)** shows flowchart illustrating the genetic algorithms operations.

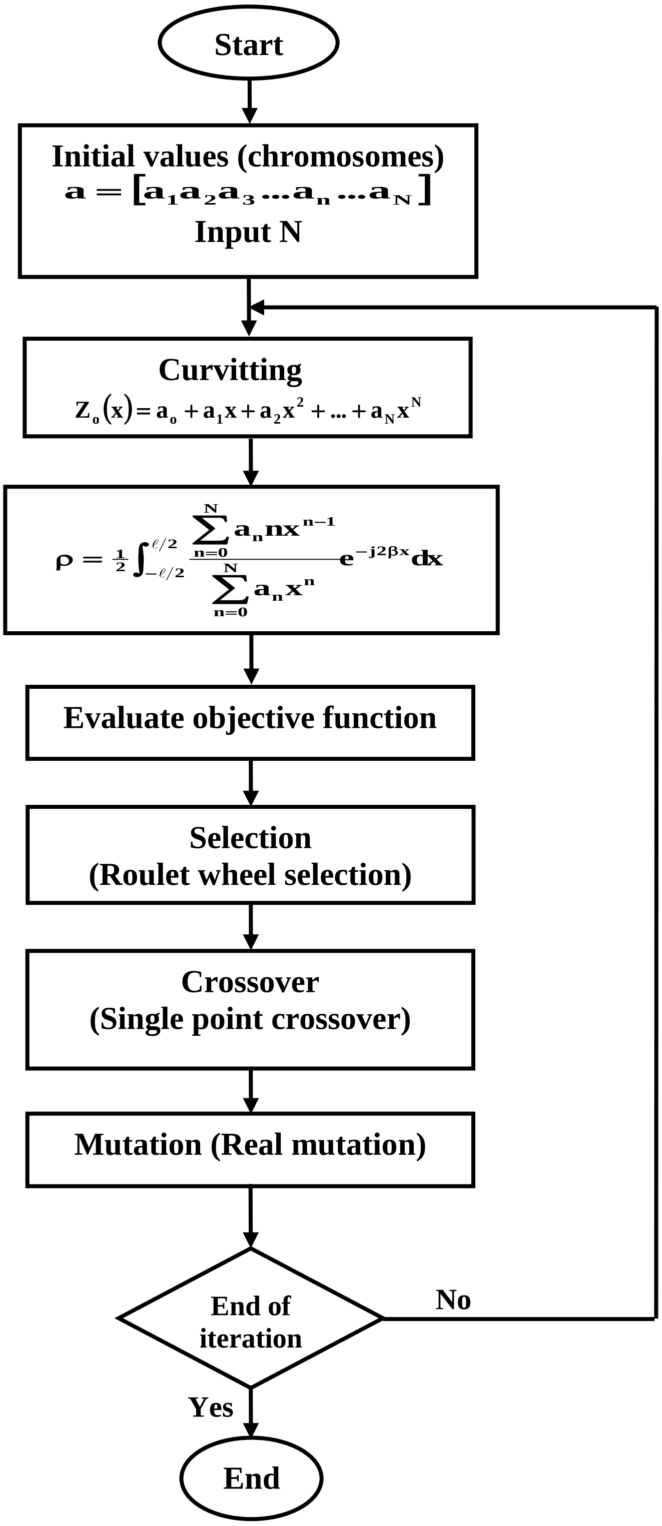

Figure (1) Flowchart illustrating the genetic algorithms

3. Results and Discussions

Many configurations of continuous tapers have been designed by various investigators. Each design has its own peculiarities regarding reflection coefficient, VSWR and the complexity of calculations of reflection coefficient. To illustrate the characteristics of a continuous taper on the present design, a comparison is made between this work and three methods (linear, exponential, and chebyshev).

Figure (2) shows the reflection coefficient patterns versus the frequency for a linear, exponential, chebyshev, and genetic algorithms tapers. It is noticed that genetic algorithms taper has less reflection coefficient than other methods (linear, exponential, and chebyshev tapers) within certain range of frequencies (10-20 GHz). For frequencies greater than 10 GHz and less than 16 GHz the maximum reflection coefficient is equal to 0.005. **Figure (3)** shows taper nominal characteristic impedance versus its length for a linear, exponential, chebyshev, and genetic algorithms tapers. **Figure (4)** shows standing wave ratio versus the frequency for a linear, exponential, chebyshev, and genetic algorithms tapers. **Table (1)** shows a comparison among four methods with respect to the maximum reflection coefficient, reflected power, and maximum VSWR. **Figure (5,6,7 and 8)** show the reflection coefficient patterns versus the frequency for best chromosomes obtained from genetic algorithms which have maximum reflection coefficient equal to 0.05, 0.075, 0.06,and 0.072 respectively within the range (10-20 GHz). **Table (2)** show the maximum reflection coefficient corresponding to best chromosomes obtained from genetic algorithms.

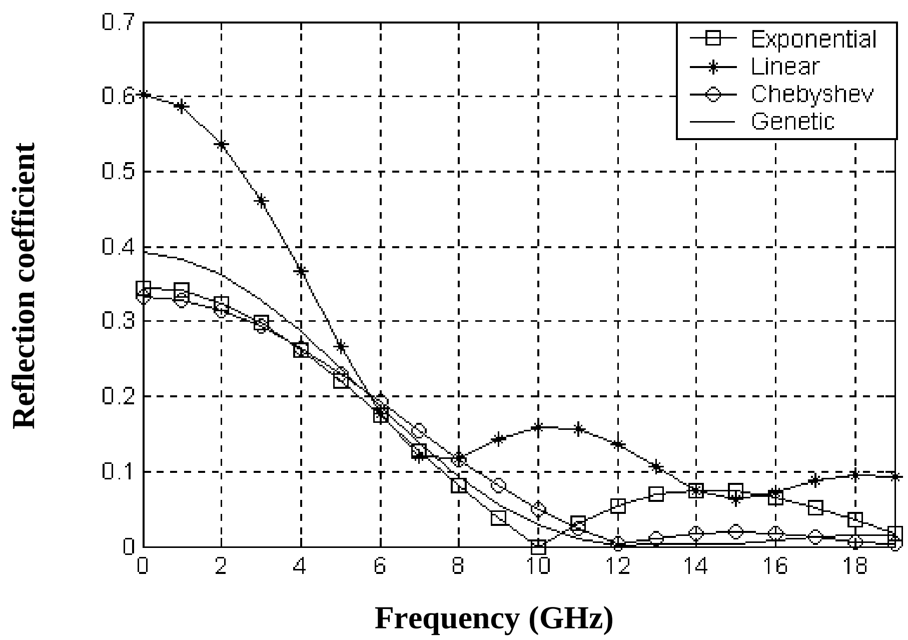

Figure (2) Reflection coefficient pattern for four methods (Linear, exponential, chebyshev, and GA methods (c_1))

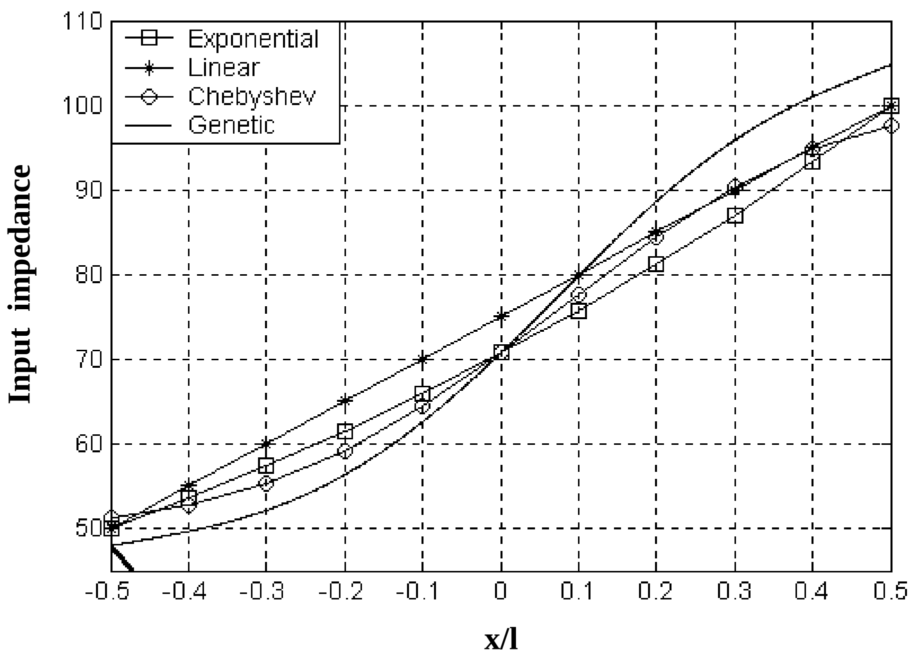

Figure (3) Taper nominal characteristic impedance versus its length taper for four methods (Linear, exponential, chebyshev, and GA methods (c_1))

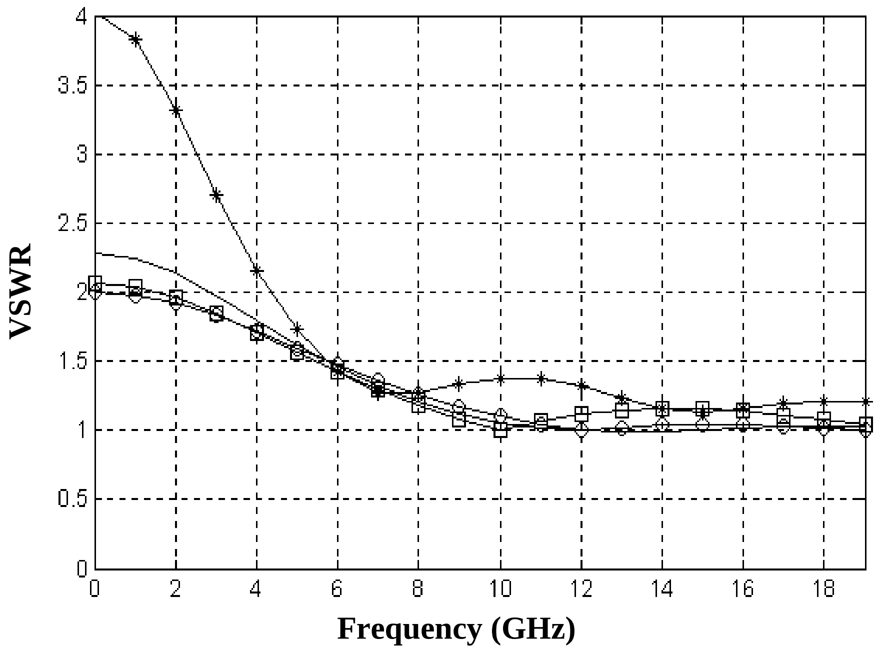

Figure (4) Standing wave ratio versus frequency for four methods (Linear taper, exponential taper, chebyshev taper, and Genetic algorithms (c_1))

Table (1) Maximum reflection coefficient within range of frequencies, and maximum VSWR for four methods

Type of Taper	ρ_{max}	Power reflected $=(\rho_{max})^2$	Maximum VSWR
Linear Taper	0.159	0.02528	1.38
Exponential Taper	0.075	0.005625	1.16
Chebysheve Taper	0.02	0.0004	1.04
Genetic algorithms	0.012	0.000144	1.02

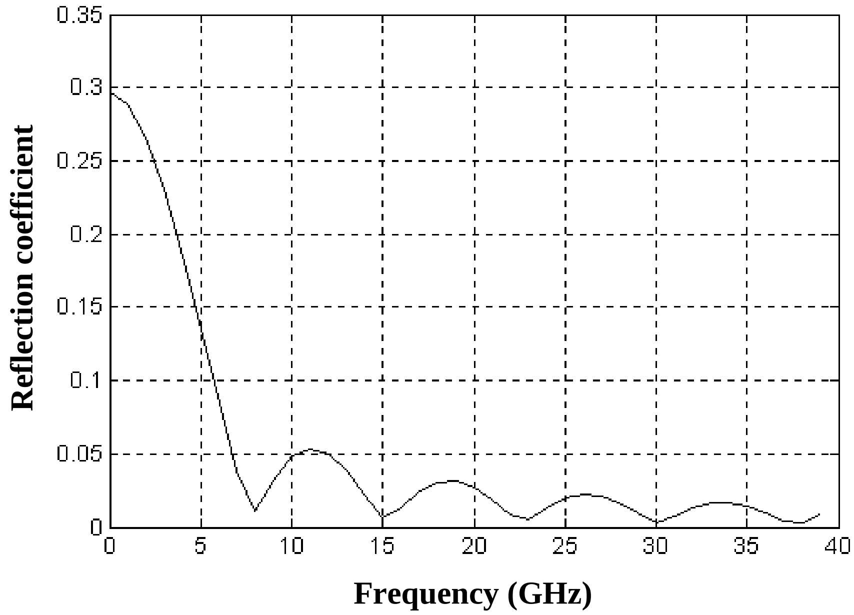

Figure (5) Reflection coefficient pattern versus frequency using GA (c_2)

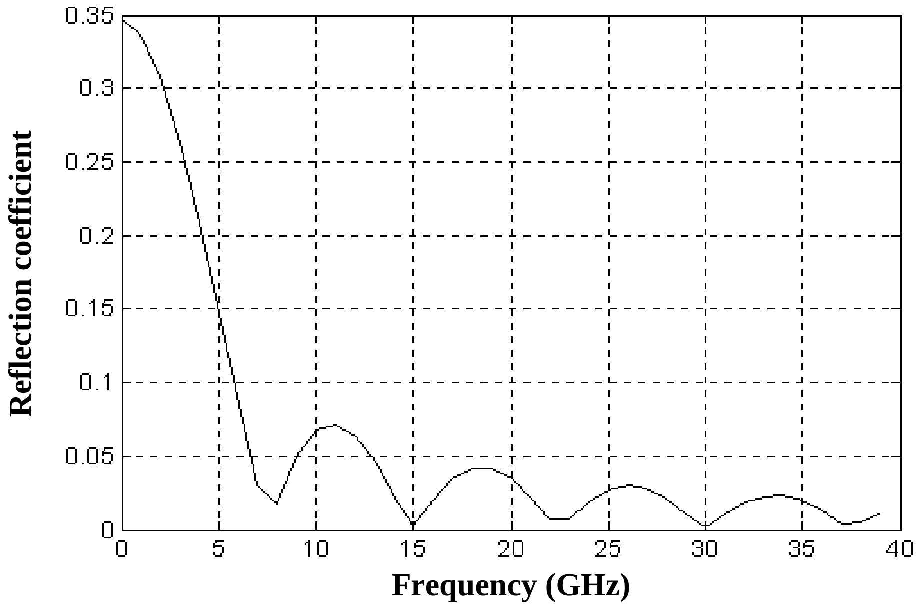

Figure (6) Reflection coefficient pattern versus frequency using GA (c_3)

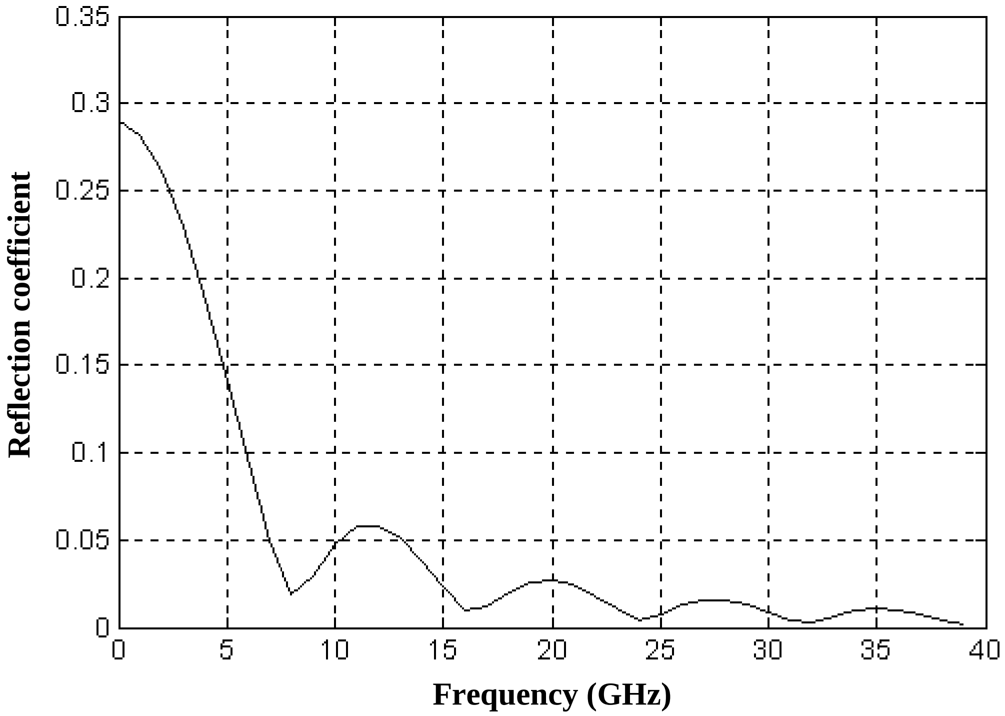

Figure (7) Reflection coefficient pattern versus frequency using GA (c_4)

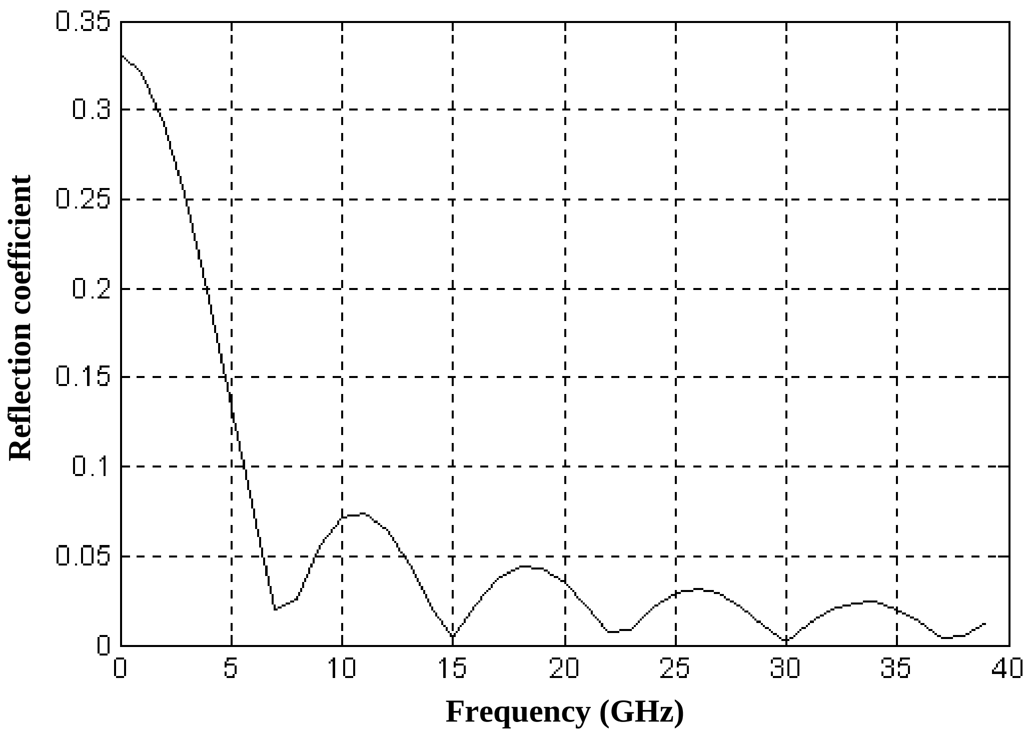

Figure (8) Reflection coefficient pattern versus frequency using GA (c_5)

Table (2) Coefficient of polynomial (genes), and maximum reflection coefficient within range of frequencies, for best chromosomes obtained from GA's

Best chromosomes	Coefficient of polynomial (genes)	ρ_{max}
C_1	1390.8 -190.1 -1461 0.0008 749.6 300.7 -240.6 -197.7 53.2 88.2 70.7	0.012
C_2	46.367 -35.019 -1.393 0.696 0.227 3.036 -8.570 -15.686 9.147 45.68 70.710	0.05
C_3	0.916 -0.07 -0.199 0.112 0.998 0.476 -3.101 0.934 20.723 50.238 70.71	0.075
C_4	0.021 -0.07 -0.056 -373.576 0.998 0.948 -3.101 7.565 5.227 47.188 75.71	0.06
C_5	0.021 -0.070 -0.199 0.112 0.781 0.457 -1.569 5.582 13.525 45.765 70.71	0.072

Figure (9) shows reflection coefficient patterns versus the frequency using genetic algorithms with maximum reflection coefficient is equal to 0.0055 (within the range of frequency 10-20 GHz). **Figure (10)** shows the relationship between input impedance Z(x) versus length, the form of this taper is unaccepted. This figure gives the taper from 68 to 87 ohm while in this approach the required taper is from 50 to 100 ohm.

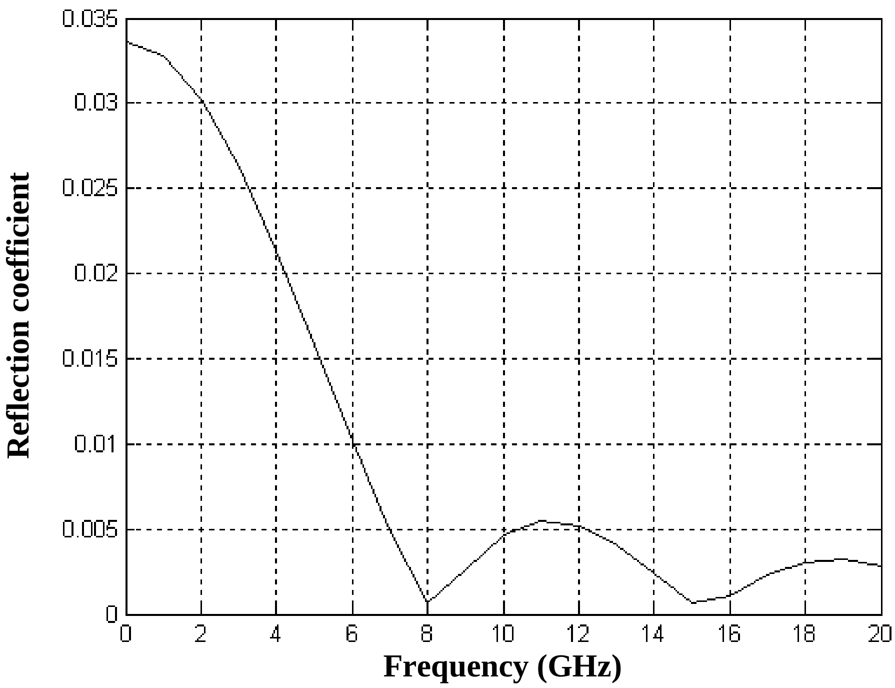

Figure (9) Reflection coefficient pattern versus frequency using GA for max. reflection coefficient of (0.0055)

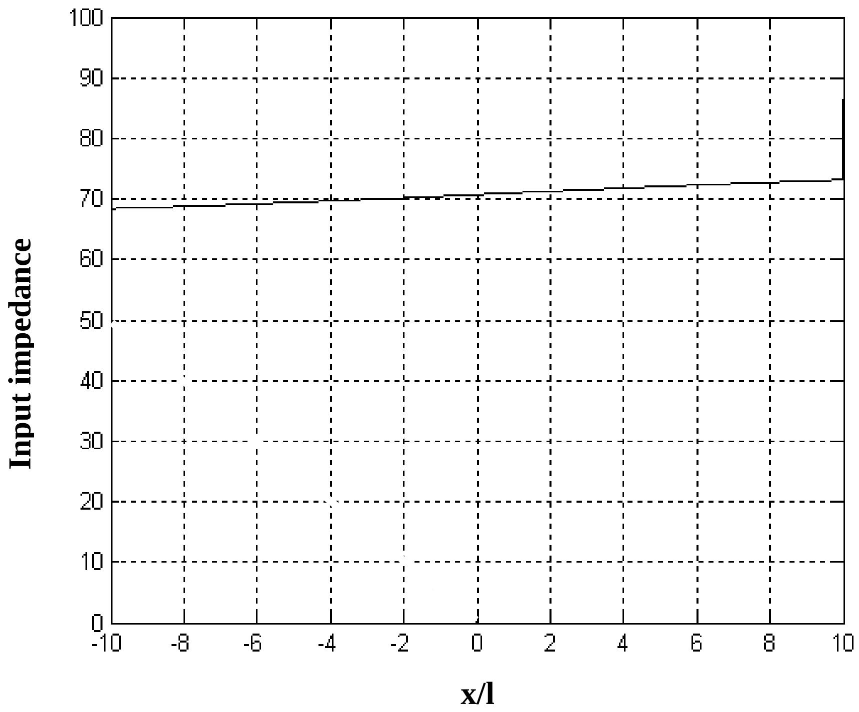

Figure (10) Taper nominal characteristic impedance versus its length taper for GA for max. reflection coefficient of (0.0055)

Above procedure can be applied in general such waveguides or microstrip line tapers. As an illustrative example, a genetic algorithm taper to match a 50 to 100 ohm microstrip line will be designed to have a maximum reflection coefficient magnitude of 0.012 for all frequencies from (10-20 GHz) as shown in **Fig.(2)**. The dielectric constant and the height of the substrate material for the taper and two (50 and 100 ohm) is (ε_r=2.2) and (h=3.2mm) respectively. The conductor pattern of taper is shown in **Fig.(11)**.

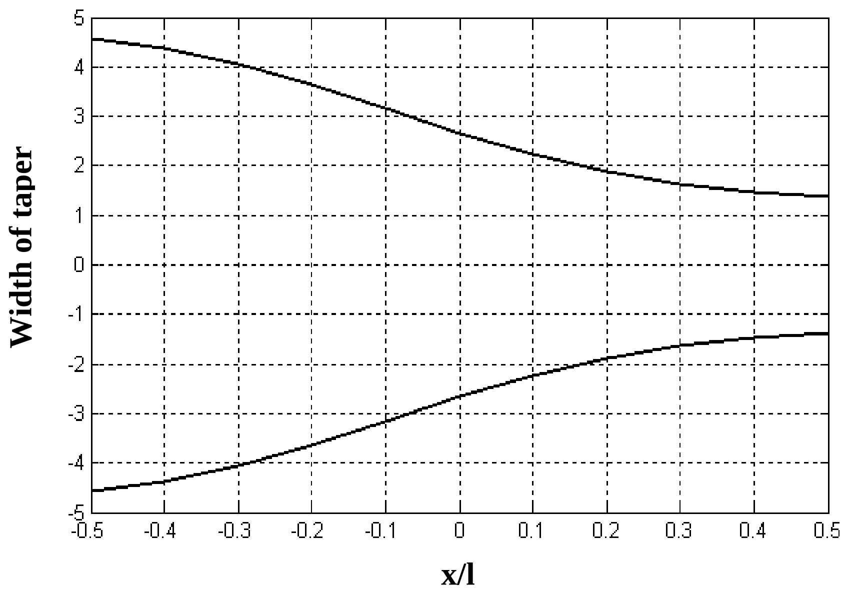

Figure (11) Conductor pattern of a continuous microstrip taper

4. Conclusions

The genetic algorithm proved to be more effective at producing good results than linear, exponential, and chebyshev tapers. The genetic algorithm gives smallest reflection coefficient from other methods (linear, exponential, and chebyshev tapers), it improves the reflection coefficient patterns by 38% from chebyshev design with certain range of frequency (10-20 GHz). The taper design using genetic algorithm gives a simple representation that reduce the mathematical form compared with chebyshev taper mathematics. Genetic algorithms can obtain very small reflection coefficient within the range of frequency, but on the other hand the characteristics impedance form obtained is difficult in practical.

5. References

1. Balanis, C. A., ***"Antenna Theory"***, John Wiley and Sons, Second Edition, 1997

2. khilla, A. M., ***"Optimum Continuous Microstrip Tapers are Amenable to Computer-Aided Design"***, AEG-Telefunken, W. Germany, Microwave Journal, May 1983.

3. Matsumaru, K., ***"Reflection Coefficient of E-Plane Tapered Waveguides"***, IRE, Antenna and Propagation, 1958, pp.143-149.

4. Klopfenstein, R. W., ***"A Transmission Line Taper of Improved Design"***, IRE, Antenna and Propagation, 1956, pp. 31-34.

5. Samii, Y. R., ***"Genetic Algorithm (GA) and Particle Swarm Optimization (pso): Evolutionary Optimization Paradigms in Modern Electromagnetic Engineering"***, Los Angeles, California 90095-1594, USA, 2004.

6. Keen-Keng, Y., and Yilong, L., "***Side Lobe Reduction in Array Pattern Synthesis using Genetic Algorithm"***, IEEE, Antenna and Propagation, Vol. 45, July 1997, pp.1117-1122.

7. Weile, D. S., and Eric, M., ***"Genetic Algorithm Optimization Applied to Electromagnetics: a Review"***, IEEE, Antenna and Propagation, Vol. 45, March 1997, pp.343-353.

8. Al-Khafaji, A. W., and J. R., Tooley, ***"Numerical Methods in Engineering Practice"***, CBS Publishing Japan Ltd, 1986.

9. Jain, L. C., and Jain, R. K., ***"Hybrid Intelligent Engineering Systems"***, World Scientific Publishing, 1997.

10. Obitko, M., ***"Introduction to Genetic Algorithms"***, Hochschule for Technik and Wirtschaft Dresden, September 1998.

11. Goldberg, D. E., ***"Genetic Algorithms in Search, Optimization, and Machine Learing"***, Addison-Wesley, 1989.