A New Method to Improve the Simulation Of Piezoelectric Transducer Using PSPICE And Genetic Algorithms

Dr. M. M. Elgazzar

Cairo, Egypt

Abstract

Piezoelectric transducer (SAW devices) is a very important device in industry but it is very difficult to simulate it using any circuit-simulation program. This paper proposes a practical method to simulate the Mason's model of piezoelectric transducer directly with no approximation for different values of the model's components using PSPICE. The paper also improves the simulated circuit component values using a Genetic Algorithms module. This optimization of the simulated circuit parameters minimizes the difference between the real output behavior of the piezoelectric transducer and the output of the simulated circuit using PSPICE. The paper also contrasts the new method with two other methods that simulate the Mason's model of the piezoelectric transducer.

1. Introduction

In the last 20 years, the signal-processing field has turned its attention to devices based on surface acoustic wave (SAW) propagation. The interest in acoustic devices is a result of the very low velocity of acoustic modes of propagation. Thus, an acoustic wave device is smaller than equivalent electromagnetic devices by the same range.[1] There are some devices like Piezoelectric transducers have electric, mechanic and acoustic behaviors. So, it is very hardly to represent them using simulation-programs like PSPICE because the mechanical and acoustic behaviors must be converted to electrical behavior in order to simulate the device. The other problem is that how to improve the result output behavior in order to reach the real output behavior of the transducer.

Another problem that face most of circuit analysts and designers that use the simulation programs when trying to achieve a desired output they starting to make trial and errors techniques in order to reach to the right values of the circuit parameters that achieve the specified output.

In this paper, a direct method to simulate piezoelectric transducer is presented, Then, a new method that combines the genetic algorithm search technique and the PSPICE program is used to optimize the simulated circuit behavior. This module could be generalized and used as an assistant for the researchers or circuit designers who tries to achieve a specific output function from any simulated circuit rather than trial and error techniques. The sections are arranged as follows : section 2 introduces the mason's Model of equivalent circuit of Piezoelectric transducer and then two methods that simulate Mason's model. In section 3, a direct method to simulate piezoelectric transducer with no approximation is presented. In section 4, a simple genetic algorithm is introduced. In Section 5 , the new method to improve the values of the simulated circuit's components in order to minimize the difference between the real output behavior of the Piezoelectric transducer and the output of the simulated circuit, is discussed. Section 6 , shows the results of applying the new method on the Mason's model and the improvements of the output behavior in contrast with the previous methods.

2. Previous Methods to Simulate the Piezoelectric Transducer

In this section, the Mason's model of piezoelectric transducer that is used in the simulation is presented. Then, two methods that simulate Mason's Model either by approximate components' values of the model or by using controlled-source rather than traditional transformer to model coupling between the electrical and mechanical systems in the model are represented. In each method, there was a clear difference between the output behavior of the simulated circuit and the real output behavior of the piezoelectric transducer.

2.1. Piezoelectric Transducers

There are two types of transducers : first, passive transducers that require an electrical energy source to produce an electrical output signal, the second is self-generation (as Piezoelectric) transducers which under mechanical excitation they produce electrical output signals without any applied electrical energy, and vice versa under electrical excitation they produce mechanical output as shown in figure 1 . Because of these two properties of self-generation and reciprocal activity , piezoelectric transducers have wide use in signal processing applications (as medical instruments) .

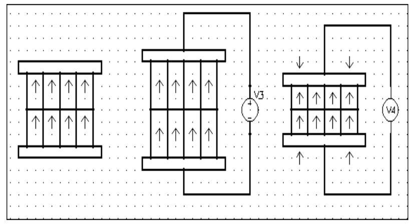


Fig. 1 The piezoelectric materials in different modes

2.2. Equivalent Circuit (Mason's Model) [2,3]

The Mason's equivalent circuit of thickness mode of piezoelectric transducer consists of a capacitance Co, a negative capacitance (- Co) -the problem in representation-, an ideal transformer and transmission line. See Fig. 2. The representation of transformer and the negative capacitance in this model were the main difficulty that faced the researcher in this field.

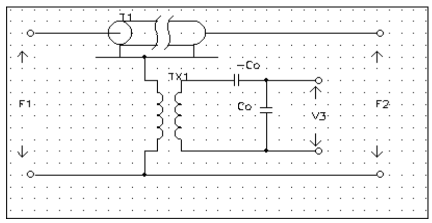
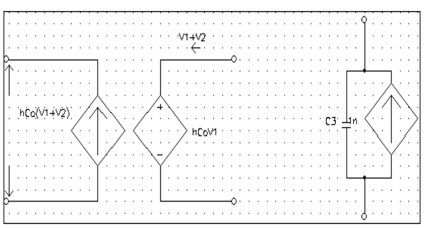


Fig. 2 Equivalent Circuit of Mason's Model

2.3 Implementation Of Mason's Model On Circuit Analysis Programs [2]

In this method , The problem of representing negative capacitance and idea transformer was solved as follows: First, they replaced the negative capacitance by a current source with parallel capacitance as show in fig.(3-a) . Second, they replaced the ideal transformer by a dependent current source and dependent voltage source as show in fig.(3-b) then fig. (4) show the final equivalent circuit.



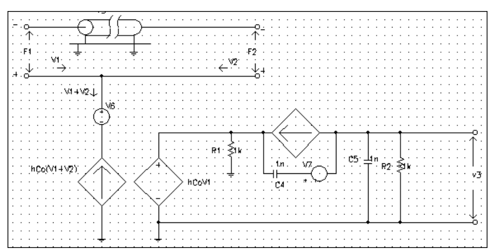


Fig.(3-a) Fig.(3-b) Fig.(4) The final equivalent circuit.

There are many disadvantages of this method [3], but from our study perspective, the main one was that the output curve (simulated force) of the simulated circuit was significantly far from the real output of the piezoelectric as shown in fig (5).

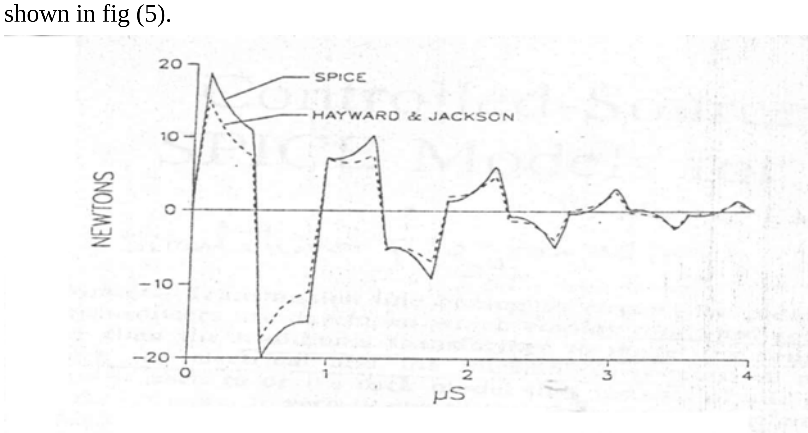


Fig 5 The output from first method compared to the real output

2.4.Controlled–Source Analogous Circuit And SPICE Models For Piezoelectric Transducers [4]

In this method, controlled sources was used with the transmission line rather than the traditional transformer to model the coupling between the electrical and mechanical system. When the traditional transformer in the first method is used, it leads to unrealizable impedance elements (negative capacitor).

The controlled-source models can be used instead of transformer so the circuits can be easily analyzed with the computer analysis programs such as PSPICE. So, the equivalent circuit must contain frequency dependent element. Although, this might seem to complicate the models, writing equations for circuits that contain frequency-dependent controlled sources is no more difficult than writing equations for circuits that contain frequency dependent impedance (capacitors and inductors).

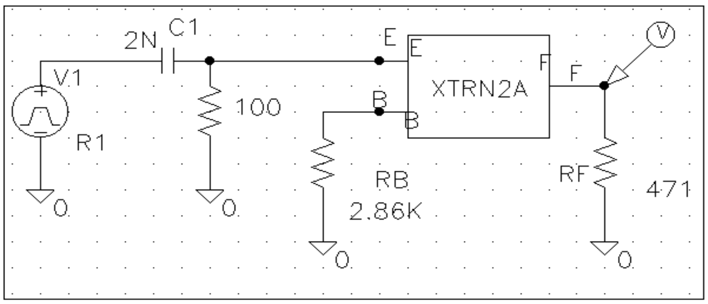


Fig.(6) show the final representation of this method.

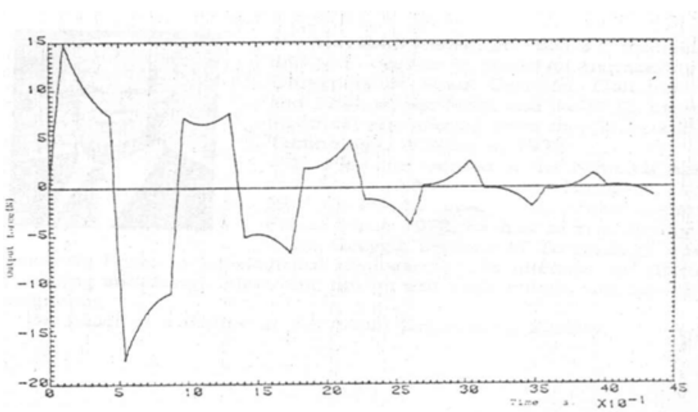


Fig 7 The output curve from method 2 compared with the real output

3. The Direct Method For Piezoelectric Transducer Simulation Using PSPICE Program

In this method, using Mason's equivalent circuit directly in PSPICE endowed with capability to handle negative capacitance and inductance simulates the piezoelectric transducer. Fig(8) show the final direct simulation circuit of piezoelectric transducer using PSPICE.

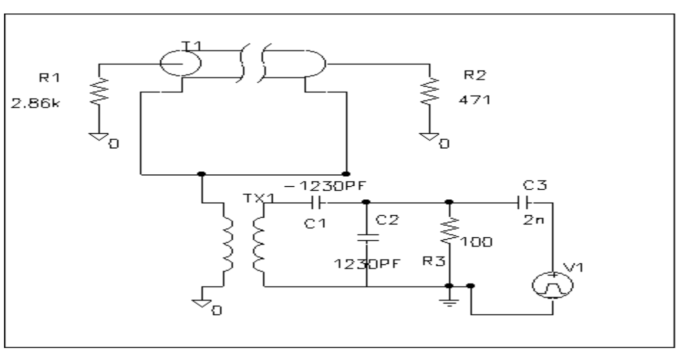


Fig (8) The direct simulation of Piezoelectric Transducer using PSPICE

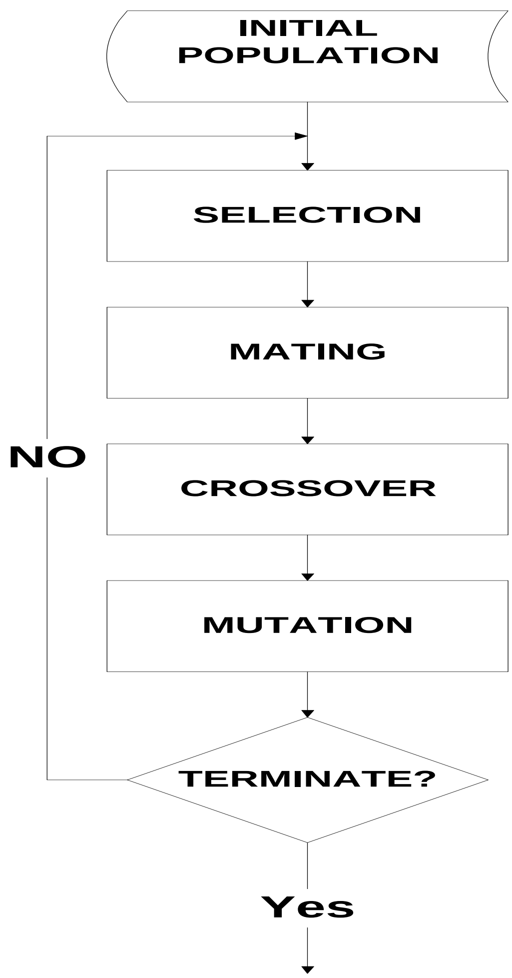
Although we directly simulate the Mason's Model with no approximation of the different components, there is still a significant difference between the real curve and simulated one
In the next section we will introduce the simple genetic algorithm and its usage in optimization and then how we use a Genetic Algorithm module to optimize circuit simulation of piezoelectric transducers.

4 . Simple Genetic Algorithm[6]

The concept of the genetic algorithm, first formalized by Holland [6] and extended to functional optimization by De Jong [K.A. De Jong, 1975], involves the use of optimization search strategies patterned after the Darwinian notion of natural selection and evolution. During a GA optimization, a set of trial solutions, or individuals, is chosen, and then evolved toward an optimal solution, under the selective pressure of the fitness function.

In general, a GA optimizer must be able to perform six basic tasks:

1. Encode the solution parameters as genes,
2. Create a string of the genes to form a chromosome,
3. Initialize a starting population,
4. Evaluate and assign fitness values to individuals in the population,



5. Perform reproduction through the fitness-weighted selection of individuals from the population, and
6. Perform recombination and mutation to produce members of the next generation.

In the following section, a new method that use the GA to optimize the simulated curve of piezoelectric transducer is discussed.

5. A New Method to improve the Simulation output of Piezoelectric Transducer

As illustrated before , in each simulated circuit for Piezoelectric transducer (even in the direct simulation) there was a clear difference between the real behavior of the Piezoelectric transducer and the simulated curve resulted from PSPICE (in fact, it is a general problem with any simulated circuit).

The new method combines the PSPICE program with a Genetic Algorithm module in order to optimize the simulated circuit design. The new method consists of 8 steps as follows :

1- Input

a- The circuit designer should specify the promising parameters and their ranges of the circuit components that he / she feels that it will effect in the output curve. In the case of Piezoelectric transducers , these parameters are the negative capacitance (-C) and the parameters of idea transformer (L1 : the primary inductance , L2: the secondary inductance, and K: the matching between L1&L2) . The values of these parameters were resulted from the direct simulation of piezoelectric transducers as in section (3) . The specified parameters act as genes of the chromosome in genetic algorithm module.

b- The other input to the Genetic Algorithm module is the desired behavior of the Piezoelectric transducer

2- Interpolation Step

a- Because the PSPICE program generate its output curve at a random points of a certain time an Interpolation step should be applied to the output of simulated curve in order to fix the comparison points of simulated and real curves.

b- Store the real curve points in a matrix Y.

3-Genetic Algorithm Module :

a- The chromosom is given to the GA with length 4 (-C, L1, L2, K)
b- The starting population (20 iteration was used)
c- The maximum generation used was 50 generation.
d- Apply Genetic Algorithms search operators : Mutation = 0.01 and Crossover = 0.85.
e- Output iteration to the PSPICE program.

4- Run PSPICE Program (at every iteration generated from GA module)

a- The PSPICE program starts its work with simulating the direct model of piezoelectric transducer as in section 3. This simulated circuit contains all the components of the circuit.
b- The output from GA module (Chromosome with 4 parameters of the 4 components) is given to the PSPICE to simulate this iteration.

5-Preparation before Comparison.

Prepare the simulated curve to the coparison in two steps :

a- Store the simulated curve from PSPICE in a text file.
b- Interpolate the output curve at the same points of the desired output
c- Store the output curve in a matrix Y1

6- Comparison

Calculate the error between simulated and real curves by this equation

ERROR=(1/N) X SUM [(Y-Y1)^2]

Where ERROR is a matrix error values that we caculated
N is the number of points in the curve.
Y is the matrix of points of t he real curve.
Y1 is the matrix of points of simulated curve.

7- Test

Test if the maximum generation is achieved. If the result is No go to step 3 and repeat if yes go to step 8

8- Output the best parameters

Sort Error matrix and choose the minimum error. The corresponding chromosome to the minimum error is the best parameter set of the promising components. We use these parameters and simulate it using PSPICE program in order to get the output curve of the simulated circuit. Fig 10 shows the flowchart of the method.

The new method could be generalized and considered as an additional module after PSPICE program as shown in fig.(11) . Most of circuit analysts and designers that use the simulation programs when trying to achieve a desired output they starting to make trial and errors techniques in order to reach to the right values of the circuit parameters that achieve the specified output. This module could be used as an assistant for the researcher or circuit designers who tries to achieve a specific output function from any simulated circuit rather than trial and error techniques.

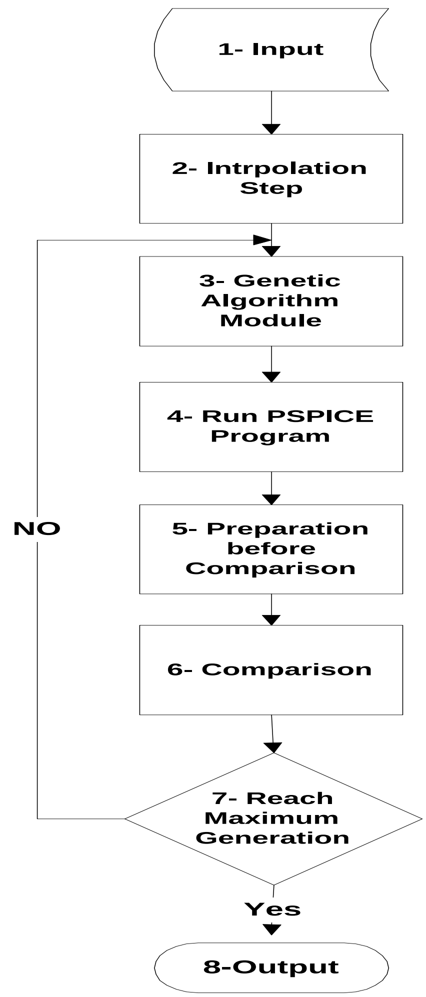


Fig 10. Flowchart of the new method

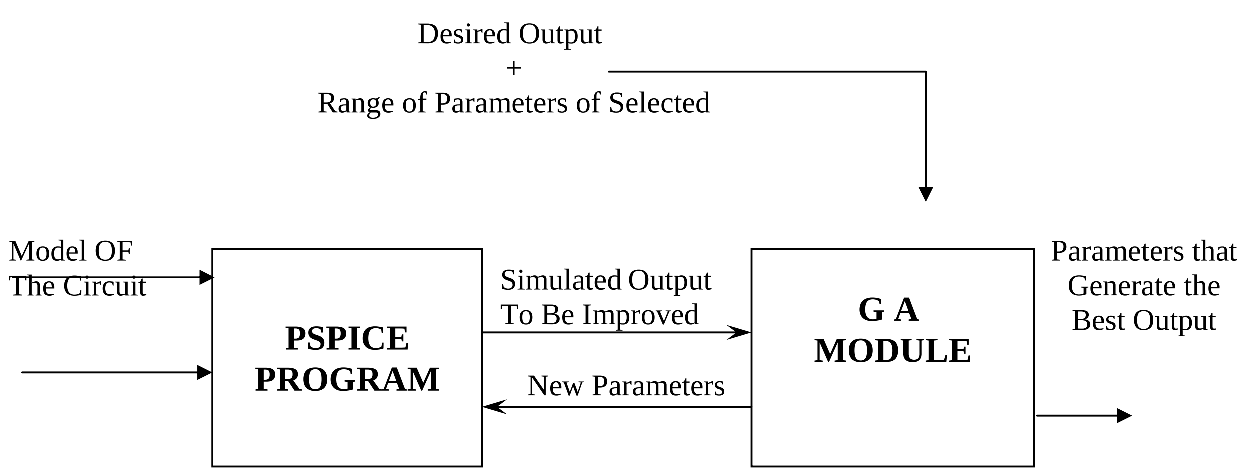


Fig 11 : The Block-diagram of combining the PSPICE and GA in the new method

6. Results

As discussed in the previous section, we apply the new method to the direct simulated circuit discussed in section 3. Fig 12 is contains the best parameters that is generated from applying the GA module. Fig 13 shows the desired (or real curve) of the Piezoelectric transducer compared with the simulated output from PSPICE program with the parameters values of figure 12 (the best parameter). We can see how the two curves are close to each other i.e., the new method could improve the simulated curve and could achieve the desired output.

```
* Schematics Netlist *

R_R1        0 $N_0001  2.86k
R_R3        0 $N_0002  100
C_C2        0 $N_0002  1230PF
T_T1        $N_0001 $N_0003 $N_0004 $N_0003 Z0=10.58K TD=430NSEC
R_R2        0 $N_0004  471
V_V1        $N_0005 0
+PULSE 0 300 0 100NSEC
C_C1        $N_0006 $N_0002  -1230PF  (C0 first gene in chromosome)
C_C3        $N_0002 $N_0005  2n
K_TX1       L1_TX1 L2_TX1 .9999      (K  second gene in chromosome)
L1_TX1      $N_0003 0 10mH         (L1 third gene in chromosome)
L2_TX1      $N_0006 0 4mH          (L2 fourth gene in Chromosome)
```

Fig 12 The best parameters generated from the GA module.

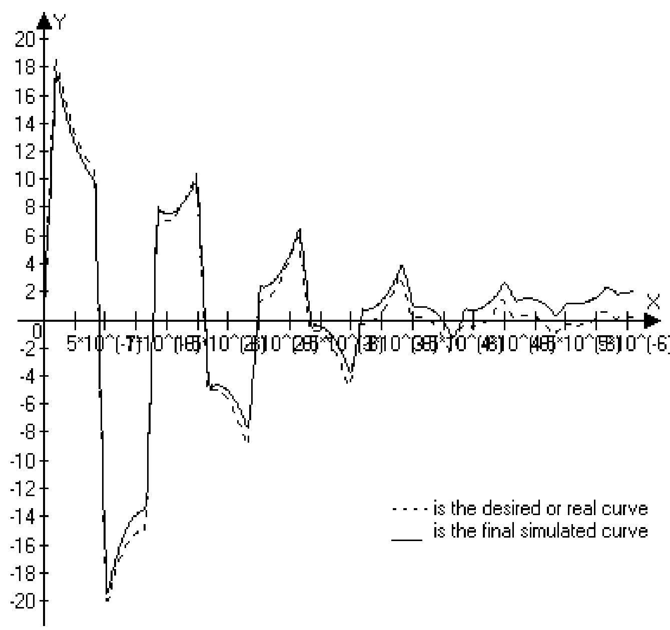


Fig 13 the final simulated output and the desired output of Piezoelectric Transducer

7.Conclusion

In this paper , we show the difficulties of simulation piezoelectric transducer and how it is a very important device in industry. Previous methods that tried to simulate this device used indirect methods to simulate it. We first simulate this device directly using PSPICE program and then we use a Genetic Algorithm module to improve the simulated behavior depending on the experience of the designer and how he/she can decide the promising parameters that will affect the output behavior and start the GA module with these parameters in order to improve their values. Finally we show how the output simulated behavior is improved using this method in contrast with the other previous methods. This new method could be used in general as an assistant method to the circuit designers to improve the simulated circuit parameters in order to achieve any desired output.

References

[1] Kai Chang , "Handbook of microwave and optical components " , Volume 1, Microwave Passive and Antenna Components, A Wiley-Interscience Publication, 1989

[2] Steven A. Morris and Chriswell G. Hutchens , "Implementation of Mason's Model On Circuit Analysis Programs". IEEE Transactions on Ultrasonic vol. UFFC-33. NO 3, May 1986.

[3] A. B. Bhattacharyya, Suneet Tuli, and Swati Majumdar . " SPICE Simulation of Surface Acostic Wave Interdigital Transducers", IEEE Transactions on Ultrasonic vol. 42, No 4, July 1995.

[4] W. Marshall Leach and Jr. , Senior, " Controlled – Source Analogous And SPICE Models For Piezoelectric Transducers ",IEEE Transactions on Ultrasonic vol. 41, No 1 , January 1994.

[5] J. Seymour. "Electronic Devices & Components ", second edition, Longman Scientific and Technical, 1981

[6] Holland J.H., Genetic Algorithms, Scientific American July 1992 (p.44-50)

[7] Mitsuo Gen and Runwei , " Genetic Algorithms and Engineering Design ", A Wiley-Interscience Publications, 1997

[8] Zbigniew Michalewicz " Genetic Algorithms + Data Structures = Evolution Programs " Second, Extended Edition, Springer-Verlag, 1992.

[9] "The Student Edition of MATLAB", USER'S GUIDE, The Matlab Curriculum Seireis, Prentice Hall , Englewood Cliffs, 1995.

[10] Franz Monssen , "PSPICE With Circuit Analysis", Macmillan Publishing, 1993.

[11] Andrew Chipperfield ,Peter Fleming , Hartmut Pohlheim and Carlos Fonseca "Genetic algorithm TOOLBOX", For Using with Matlab Ver 1.2 User's Guide.

[12] John Keown ,"PSPICE and Circuit Analysis", Ver 5.1, Second Edition, Macmillan Publishing, 1993.

[13] J. Michael Johnson and Yahya Rahmat-Samii, "Genetic Algorithms in Engineering Electromagnetics", IEEE Antennas and Propagation Magazine, Vol .39 , No.4, August 1997.