Research on Fault Diagnosis of Mixed-signal Circuits Based on Genetic Algorithms

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Abstract*—As the fault modes of mixed-signal circuits growing, aiming at the features for its signal are both analog and digital amount, the paper analyzed that the fault diagnosis program of mixed-signal circuits with genetic algorithms by using SABER simulation method to inject faults and data collection based on a brief discussion of basic principles and operation of genetic algorithms, focused on consideration for the fitness functions of genetic algorithms, and then selected an optimization genetic algorithm to a specific airborne DC converter circuit's fault diagnosis, verifying the effectiveness of the method, provided a new diagnostic method for mixed-signal circuits.

Keywords-mixed-signal circuits; fault diagnosis; genetic algorithms; SABER simulation; fitness function.

I. INTRODUCTION

Currently, as the complexity structure of electronic circuits growing, most electronic circuits are both analog circuits and digital circuits, at the same time, nonlinear characteristics of circuit components are becoming increasingly apparent, and input & output signals are more complex, even if data or extraction of data feature for the measured points also becomes difficult, which makes the traditional method of fault diagnosis difficult to solve the problem effectively, therefore, seeking a new fault diagnosis method of mixed-signal circuits becomes very important.

The traditional fault dictionary method is the most widely used and most effective way, which to solve pure analog circuits or digital circuits has a large advantage, but has a disadvantage for fault diagnosis of mixed-signal circuit. Therefore, aiming at the features for the amount of analog and digital, the paper brief discusses the basic principles and operation of genetic algorithm, selects failure modes by FMECA, and uses the SABER simulation method to inject faults[1,2] and data collection. Focusing on the fitness function problem of genetic algorithm to research on fault diagnosis program of mixed-signal circuit based on genetic Algorithms [3–6], an optimized genetic algorithm are used to process the collected data, establishing the fault database. The method can reduce the work of fault dictionary, to some extent, reducing the work of the fault diagnosis for mixed-signal circuits.

II. THE BASIC PRINCIPLES OF GENETIC ALGORITHMS

Genetic Algorithm is an adaptive probabilistic global optimization search algorithm in computer, which starting from the initial populations, repeating the genetic operations, so that populations produce more offspring populations to adapt to the environment, and finally evolved into one of the most appropriate individuals to survive, this individual is the desired optimal solution. In process of genetic algorithm optimization, the fitness function is the only objective function, which randomly generated many starting points and started search in high-dimensional feasible solutions space.

A. Operating Mechanism

Genetic algorithms mainly reconstructed some form of individuals among populations through genetic operating, gradually approaching the optimal solution. The basic operators of genetic operating included selection, crossover and mutation, the effect of operation is closely related with the operator probability, encoding methods, population size, initial population and the fitness function. Genetic operating methods or operating policies determined by the specific problems, and it is directly related to the individual encoding. Figure 1 shows the flow chart of the basic genetic algorithm.

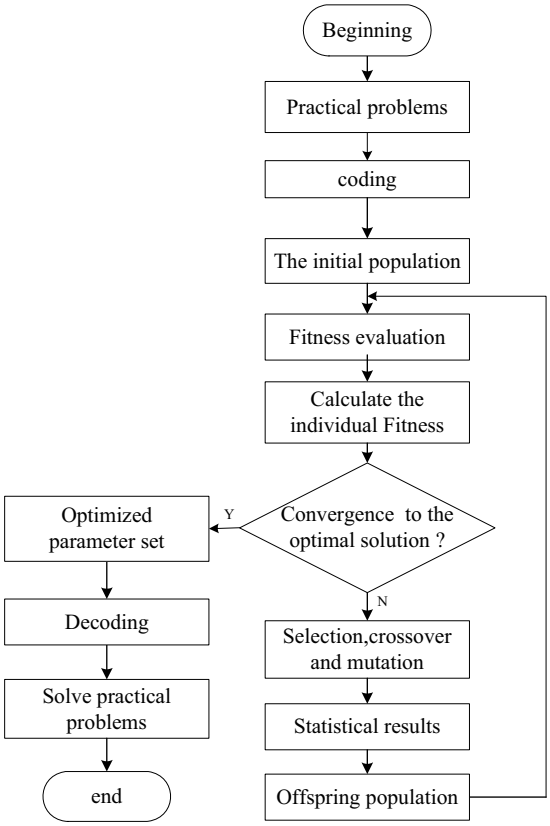

Figure 1. Flow chart of the basic genetic algorithm.

Selection is the process of generating new populations by the strong individual selected from the old population, according to the fitness value of the objective function of the encoding strings. In general, the higher fitness value of the

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encoding string, then the greater chance of survival and reproduction in the population, that is, an excellent living environment for the individual has the more opportunity to reproduce, so that fine features can be inherited from generation to generation. Crossover is the reorganization of two encoded strings, which is critical different from other traditional optimization method. Crossover have two steps, the first step is random taking the two encoding strings to match from the population, then using a certain way to swap the information of two encoded strings to produce a string of new code. Mutation randomly selected some individuals from the population on a certain variation probability. Aiming to the selected individuals, in which the coding required to random generate the numbers which greater than 0 is less than 9 to replace the original number; if encoding method is the binary encoding, the mutation achieved the conversion between 0 and 1.

B. Encoding Methods

Encoding is transforming the parameters of the practical problem into a genetic operating by a certain structure encoding string or individual. There are common three types encoding: binary encoding, real encoding, matrix encoding. Binary encoding transformed the solution of decimal numbers or the practical problem into binary form expressed by 0 or 1, and string length determined by the specific problems. As the binary encoding may have some quantization error, it only applies to the general genetic algorithm. Real encoding is that real number is as an encoding string, suitable for the solving of the high-dimensional or complex optimization problem. Matrix encoding is using the matrix form to encoded individual, which is a simple, direct way to represent the various combinations, and expand the search of solution.

III. THE METHOD RESEARCH ON FAULT DIAGNOSIS OF MIXED-SIGNAL CIRCUITS

The nature of genetic algorithms search for optimal solutions is based on the individual fitness of each population, through selection, crossover and other operations iterative, constantly searching for individuals with better fitness, and ultimately getting the optimal solution. Fitness function is the standards of evaluating the quality of individual, which will directly affect the process of genetic algorithm searching optimal solution, and common forms of definition for fitness function are two main forms[7~11]:

(1)Directly translated the objective function into the fitness function

$$\mathrm{Fit}\left(\mathrm{f(x)}\right)=\begin{cases}\mathrm{f(x)} & \text{Maximzing the objective function}\\ \mathrm{-f(x)} & \text{Minimizing the objective function}\end{cases} \quad (1)$$

This fitness function is easy to operate, but there are two problems in applications: it does not meet the requirements of non-negative, and due to some of the objective function value may be very difference, the average fitness value may not reflect the populations' average performance, impacting on the algorithm results.

(2) Construction method

$$\mathrm{Fit}\left(\mathrm{f(x)}\right)=\begin{cases}\left|\mathrm{c-f(x)}\right| & \mathrm{c}\neq\mathrm{f(x)}\\ 0 & \mathrm{c}=\mathrm{f(x)}\end{cases} \quad (2)$$

Where c has a variety of selection methods, it can be a suitable input values and also can used the most value of the objective function. Because the parameter c is often prior assessment, its selection often affects the sensitivity of the fitness function, affecting the performance of genetic algorithm.

A. Optimization of fitness function of genetic algorithms

In order to overcome the uncertainty of the traditional genetic algorithm fitness function, and the fitness function changes along with the input space of the individual, so that the fitness function can be more reasonable evaluation of the individual, and further complete the genetic searching, at the same time, the paper introduced two improved fitness function:

$$\mathrm{Fit}\left(\mathrm{f(x)}\right)=\begin{cases}\mathrm{C^{+}-f(x)} & \text{when } \mathrm{f(x)<C^{+}}\\ 0 & \text{others}\end{cases} \quad (3)$$

Where: $\mathrm{C^{+}}=\|\mathrm{f(x)_{max}-E[f(x)]}\|_2+\mathrm{E[f(x)]}$, $\mathrm{E[f(x)]}$ is the mean value of the objective function, the improved fitness function can not only ensure the fitness function non-negative, but can make the fitness function value changes along with the input space of the individual, improving the competitiveness of the individual.

$$\mathrm{Fit}\left(\mathrm{f(I_{ij})}\right)=\frac{\left|\mathrm{X(i,j)}\otimes\mathrm{X}\right|}{\sqrt{\left|\mathrm{X(i,j)}\otimes\mathrm{X(i,j)}\right|\left|\mathrm{X}\otimes\mathrm{X}\right|}} \quad (4)$$

Where: $\mathrm{X(i,j)}$ is the signal sequence for the ith kind failure in the jth test point, corresponding to the individual $\mathrm{I_{ij}}$, the signal sequence of test points to be identified is X, $\left|\mathrm{X(i,j)}\otimes\mathrm{X}\right|$ is the convolution of the sequence.

When genetic algorithms applied to the practical circuits to fault diagnosis, the selection for the fitness function according to the requirements of the specific circumstances, such as a tolerance circuit for analog circuit fault diagnosis problem, if the problem has been attributed to the fault diagnosis equation f (x), then the fitness function can be expressed with (5):

$$\mathrm{Fit}\left(\mathrm{f(x)}\right)=\mathrm{f(x)_{max}-f(x)+k\left(f(x)_{max}-f(x)_{min}\right)} \quad (5)$$

Where: $\mathrm{k>0}$, $\mathrm{f(x)_{max}}$ and $\mathrm{f(x)_{min}}$ is respectively the maximum and minimum for the current function; *k* is the parameters which controls the ratio of the current maximum and minimum fitness value.

B. The case of fault diagnosis

Taking a certain type of airborne DC converter circuit for example, the DC converter circuits are mainly composed of amplifier, DC power supply, rectifier diode, nor gate, the oscillator and other components. The DC input voltage of the circuit is 288v, and the output DC is 14v. Its signal are both analog and digital amount, is a mixed-signal circuit. The SABER simulation model of DC converter circuit shows in Figure 2:

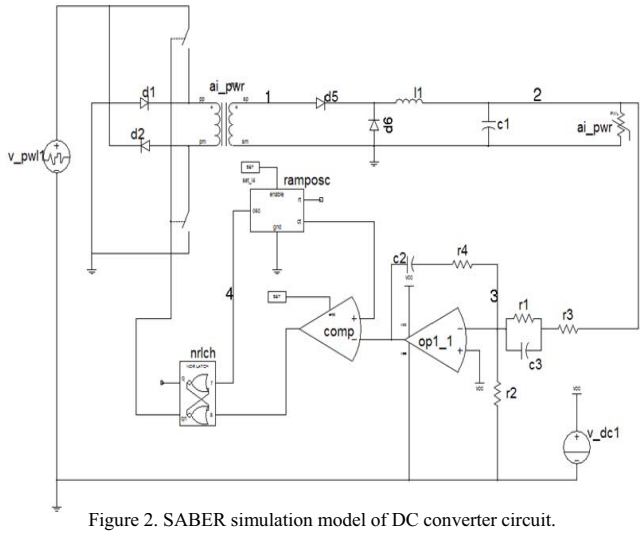

Figure 2. SABER simulation model of DC converter circuit.

➢ *Collecting data*

As the multi-fault combinations of circuits are great, single-fault is only considered in the paper. By analyzing the circuit topology[12~14], choosing the four get more information test points from 1 to 4, in which test points 1 to 3 are the analog and voltage values are expressed with V1, V2, V3, and test point 4 is digital, the value is expressed with Y4.DC conversion circuit has 47 kinds of single fault modes, combined with Failure Mode Effects and Criticality Analysis and sensitivity analysis, determined focusing on the following 12 kinds faults: (1) capacitor C1 short; (2) capacitor C2 open; (3) Enable of the comparator comp block; (4) output of the comparator comp block; (5) diode d2 short; (6) diode d5 short; (7) inductance l1 open; (8) the s of nor gate block; (9) the output of opt_1 amp open; (10) the output of opt_1 amp short; (11) resistance r2 open; (12) resistance r3 short; respectively, using *f1-f12* to express, the normal state expressed with F0. Injected fault with SABER simulation software, analog signal selects the time of fault modes occurring fault in the focus test point, as shown in Table 1:

TABLE I. FAULT DICTIONARY (IN TIME)

Faullts	n1	n2	n3	Y1
f0	1. 9442u	56. 848u	21. 487u	1. 0
f1	1. 7445u	0. 01581	20. 0158	1. 0
f2	4. 7407u	137. 31u	13. 598u	0. 0
f3	925. 35n	10. 698u	10. 739u	1. 0
f4	1. 6021u	10. 698u	10. 739u	0. 0
f5	433. 25n	28. 107u	21. 504u	1. 0
f6	4. 6396u	29. 279u	21. 032u	1. 0
f7	346. 11n	463. 76u	380. 70u	1. 0
f8	1. 5554u	42. 271u	8. 2989u	1. 0
f9	3. 3893u	10. 698u	67. 344u	1. 0
f10	301. 51n	17. 239u	12. 313u	1. 0
f11	3. 1711n	37. 489u	18. 455u	1. 0
f12	4. 6396u	31. 118u	19. 19u	0. 0

In fact, no matter what failure mode or type (such as component failure, module fault, etc) needs to be diagnosed, if only an integer-coded, fault-wise table can be constructed, the genetic algorithms can be used to research the optimal solution. Aiming to the data obtained from the circuits, we proposed a kind of category criterion, then obtaining the integer-coded fault-wise table:

TABLE II. INTEGER-CODED FAULT DICTIONARY

Faullts	n1	n2	n3	Y1
f0	1	3	2	1
f1	1	4	2	1
f2	1	2	1	0
f3	5	2	2	1
f4	1	2	2	0
f5	4	2	2	1
f6	1	2	2	1
f7	4	4	4	1
f8	1	3	1	1
f9	1	2	3	1
f10	4	2	2	1
f11	1	3	2	1
f12	1	3	2	0

However, a problem that the same integer-coded corresponding to different failure modes will produced, in order to the problem, some papers proposed the solutions. As in [15], we can get the simplified integer-coded fault dictionary:

TABLE III. SIMPLIFIED INTEGER-CODED FAULT DICTIONARY

Faullts	n1	n2	n3	Y1
f0	1	3	2	1
f1	1	4	2	1
f2	1	**2**	1	0
f3	5	2	2	1
f4	1	2	2	0
f5	4	2	2	1
f6	1	2	2	1
f7	4	4	4	1
f8	1	3	1	1
f9	1	2	3	1
f10	4	2	2	1
f12	1	3	2	0

➢ *Processing Fault data*

The collect data form the parameter set under the actual failure mode, assuming that there is a fault of the test points signal sequence X to be identified, we have to determine the failure mode of the signal sequence, that is, looking for matching or similar signal in the above parameters set. The specific steps [6] using genetic algorithms to identify signal are as follows:

(1) Encoding and decoding: the data for the twelve types known failure modes and the corresponding four test points do

the mean value, normalized as a reference standard. For two fault parameters (i, j) are encoded using binary encoding, let k1, k2, respectively, the encoding length of the two parameters, the decimal decoding of the individual's previous k1 bits is i, and the decimal decoding of the individual's last k2 bits is j, that is, the code length is k1 + k2;

(2) Generating the initial population: a code string with length k1+k2 random produce binary string, and can produce a certain number of individuals populations, setting the populations size;

(3) Calculating the fitness: an improved fitness function (4) was used to calculate the fitness value of each individual, monitoring and evaluating the individual fitness;

(4) Operating operator: The proportion operator as select operator, crossover operator and mutation operations, respectively, is using single-point crossover, uniform mutation operator. Individual choice probability as follows:

$$P_{ij} = \frac{f(I_{ij})}{\sum_{j=1}\sum_{i=1} f(I_{ij})} \tag{6}$$

Crossover probability will choose among 0.6 to 0.9, and mutation probability will choose among 0.001 to 0.1, set the termination of the evolution algebra, than search the optimal solution similar to the failure mode.

Let the test fault point X = (1.6650u、43.001u、8.312u、1.0), then using the above method and procedure, we can detect the fault easily.

IV. CONCLUSTION

The traditional fault dictionary method has some limitations to fault diagnosis of mixed-signal circuits. This paper researched on the fault diagnosis of the mixed-signal circuits from the basic theory of genetic algorithms, combining with simulation software, based on the characteristics of mixed-signal circuit and the optimal fitness function. The improved fault dictionary method based on genetic algorithm can avoid the complexity of digital amount, avoiding the special processing for digital, and the analysis of case shows that the method with the feasibility, effectiveness and practicality.

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