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Optimization method of complex electronic device test point

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ABSTRACT

In terms of complex electronic systems, in order to enhance the test efficiency and reduce the test cost, an optimization method of analog circuit test point combining with fault dictionary and branch and bound is proposed. It adopts fuzzy set and fault dictionary as tools, and takes fault detection and fault isolation as constraint condition, thus to build a 0-1 programming mathematical model for test point optimization, which is solved with branch and bound. Finally, it simulates and verifies the method with classical test optimization circuit. The simulation result indicates that the above method can realize rapid optimization of test point on the premise of guaranteeing the demand of fault diagnosis, providing guidance for test implementation.

Key words: complex electronic system; fault diagnosis; test point; test sample; fault dictionary; branch and bound

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INTRODUCTION

Complex electronic systems are usually with characteristics, such as large scale, long life cycle, key mission, high reliability, constant variation and complex network features. For example, take Integrated Modular Avionics (IMA) [1] as the typical representative, it is the highest stage of the development of avionic architecture currently. Complex electronic systems are with high rate of defect and cannot guarantee the reliability. A data survey made by the United States indicates that failure probability of F-22 is twice that of F-15 and F-16. Due to the existence of component tolerance, the test diagnosis of analog circuit is rather difficult; therefore, conducting researches on test diagnosis methods aiming at analog systems is significant.

The quality and efficiency of a diagnostic system depends on the fault information obtained from the system [2], while the sources of fault information are distributed among test points in the system. Considerable researches on fault diagnosis give tacit consent to the condition that test points have been reasonably configured in advance. In fact, restricted by the cost of overall test, configurable test resources and other factors, it is impossible to configure test resources and test for all test points. Through test point optimization, it is completely possible to obtain the fault resolution ratio as that obtains in the test of all the test points, by selecting those test point sets with the largest fault information. Recently, determining the optimal number of test points and its distribution for a specific diagnostic system has drawn attention from people [3].

CONCEPT OF FUZZY SET AND FAULT DICTIONARY

The selection principle of test point is to minimize the number of test points on the premise of isolating all faults in the fault set. Therefore, the selection process of test points is just the process of fault isolation. Fault isolation means all concentrated faults can be separated through test vectors, it usually has criterion as equation (1) [4].

$$\sum_{k=1}^{n}[V_k\,(NOR) - V_k(F_i)]^2 \geq 0.5n \qquad (1)$$

Therein, $V_k(NOR)$ represents the normal voltage of node *k*, $V_k(F_i)$represents the fault F_i voltage of node *k*, and *n* represents the number of test points. Due to the component tolerance,$V_k(NOR)$,$V_k(F_i)$ refer to an interval rather than a point. Therefore, equation (1) cannot be directly used in reality. In order to solve this problem, divide each element value of each test vector into several regions, and the central value of each region represents the average value of adjacent elements. Then, expand 0.7 V for the central value to the left and right, in order to form an interval of test values, which is called fuzzy region. All fault modes falling in the same fuzzy region constitutes a fuzzy set. Different fuzzy sets can be separated with the number of fuzzy sets(N_i, A_j). $N_i$represents the node number, and A_j represents the *j* fuzzy set. All fuzzy sets of test points form the table of fuzzy sets, which reflects the division situation of fuzzy sets for each test point, and can be obtained through circuit simulation and division of fuzzy sets generally [5].

In the foregoing discussion about fuzzy sets, the number of fuzzy sets is defined in order to separate the corresponding fuzzy sets of different test points. (N_i, A_j)represents the *j* fuzzy set $A_j$of test points N_i. A fuzzy set contains several fault modes, all of which fall in the same fuzzy region. In terms of test pointsN_i, there are *m* fuzzy regions, which are respectively numbered with the figure of fuzzy region center. Therefore, all fault modes in the same fuzzy set correspond to the same number. In this way, all fault modes contained by fuzzy sets are with one to one correspondence with certain numbers. For test point sets and fault sets in certain discourse domain, according to the above method, all fault modes have established the mapping relationship with all test points in the form of number, which is the fault dictionary. In a word, the fault dictionary is the set of behavior test points and it is equivalent to a matrix with fault sets as the columns and number of corresponding fuzzy regions (fuzzy sets) as elements, marked as *M* . Any row of *M* is called a fault code.

OPTIMIZATION MODEL AND SOLUTION OF TEST POINTS

This section adopts fault dictionary as the tool, and starts from the constraint of fault isolation, to build an integer programming mathematical model and solve with branch and bound for the optimization of test points.

Modeling of Test Point Optimization Based on Fault Dictionary:

It has been shown clearly that the requirement of selective preference of test points is to minimize the number of test points on the premise of isolating all faults in the fault set *F*. The successful isolation of faults means all faults have corresponded to the test information, which makes them separable. In terms of fault dictionary, it requires endowing a unique fault code for any fault in the fault set *F*, namely all fault codes are different.

Firstly, two basic requirements of test point optimization are described:
(1) Test point optimization can cover all faults in the given fault set *F* ;
(2)Test point optimization can isolate all faults in *F* .

The first problem is that the fault feature vector of the fault set F has at least one column containing a non-zero integer for any $f \in F$, namely, at least one test point can detect this fault. The second problem is that for any two different faults, $f_1, f_2 \in F$, their corresponding fault feature vectors are different. Based on the assumed feature vector, the following principle summarizes the optimization of test points into a modeling issue of algebraic combinatorics

Principle 1[6]: Given that F represents the fault set of the system, T represents the test point set of the system, and M represents the fault dictionary, then fault detection and fault isolation can be summarized into two points as below:

(1)When and only when M contains no column with at least a non-zero integer, *T* can detect all faults in the given fault set *F* ;
(2)When and only when all columns of *M* are different, *T* can isolate all faults in the given fault set *F*.
Obviously, when and only when all columns of *M* are different, test point set *T* can isolate all faults in the given fault set *F*.

Based on the above conclusion, the modeling of optimization of test points is as follow: to select the minimum column subset of *M*, make all these column subsets form a submatrix with different rows, then the test points of corresponding column subset is the optimal set of test points.

The above issue is further described through the equation as below. Taking the binary vector $X= (x_1, x_2 ,..., x_m)$ into consideration, its dimension is the same with the column number of matrix *M* . If and only if $x_j = 1$ represents the *j* column of *M*, then *X* can be regarded as the subset selection of *M*. Given that the row number of *M* is *n* , $I= (1,1,...,1)^T$ contains $n(n+1)/2$ vectors with elements of 1. To define a matrix *A* with $n(n+1)/2$ rows and *m* columns, each row R_{ij} *of A* corresponds to two rows R_i *and* R_j *of M* . To define $R_{ij} = R_i \oplus R_j$($\oplus$ represents EOR operation) then the condition $AX \geq I$represents that the subset consisting of solution vectors selected by X has no identical row. Then, the optimization issue of test points can be represented by equation (2):

$$min \sum_{i=1}^{m} x_i$$
$$s.t. AX \geq \mathrm{I}, x_i = 0 \; or \; 1 \tag{2}$$

MODEL SOLUTION BASED ON BRANCH AND BOUND

Among the common methods of solving 0-1 integer programming issue, there are identical, Branch And Bound (BAB), etc. Therein, BAB can guarantee the global optimum and avoid exhaustive search. It adopts an algorithm procedure similar with dividing and ruling, which aims to divide the feasible region into small sets continuously and find the optimal solution among small sets.

In order to explain the general principle of BAB, this paper sets the minimum integer programming issue P and corresponding relaxation issue P_0 as equation (3).

$$P\colon \begin{cases} \min z = cx \\ Ax \leq b \\ x \geq 0, x_i \in Z \end{cases} \quad P_0\colon \begin{cases} \min z = cx \\ Ax \leq b \\ x \geq 0, x_i \in Z \end{cases} \tag{3}$$

To solve the relaxation issue $P_0$of Pat first. The optimal solution of P_0 disagrees with the integer condition of P , then select a non-integer component $x_i = a_i$, and add an integer constraint $x_i \geq [a_i] + 1$ or $x_i \leq [a_i]$ on the basis of constraint conditions, therein, $[a_i]$ represents the integer part of $[a_i]$, thus to form two linear programming issues. BAB is to divide the feasible region F of P_0 into two subdomains $F_1$and F_2 through adding an integer constraint every time, while $F_1$and$F_2 (F_1, F_2 \subset F)$ are called branches. If the solution of sublinear programming cannot meet the integer conditions, then repeat the above process; if a solution meeting the integer condition is found out, then a feasible solution is obtained. Its objective function value is a bound, which serves as a basis of measuring other branches, known as demarcation. The algorithm procedure of BAB solution is as follows:

Step 1.Remove 0-1 requirement of the variable and obtain the minimum of objective function. If the solution is an integer, then the operation stops; otherwise, fix $x_i = a_i$ and turn to Step 2.

Step 2.Based on the original problem or the previous subproblem, add two constraints respectively to form two subproblems : the first subproblem is$x_i \leq [a_i]$; the second subproblem is $x_i \geq [a_i] + 1$.

Step 3.The principle of branches: non-branching for invalid solution; non-branching for integer solution; if the minimum value of non-integer solution and its corresponding objective function is larger than that of the existing integer solution and its objective function, then it is non-branching. Except the foregoing three situations, others should turn to Step 2 branch.

Step 4.If no further branching can be obtained, compare the integer solutions, and the minimum objective function is the desired optimal solution.

INSTANCE VALIDATION

Take the circuit in Figure 1 as an instance, whose fault dictionary is indicated by Table 1. Except unfaulty conditions, the dimension of this fault dictionary M is 18×11, and the binary vector represents the column selection of M, namely the test points. Take EOR operation for every two rows of M to obtain the constraint matrix A, with the row number of 153 and column number of 11. Substitute the above conditions and go through BAB, and then the solution X = (1, 0, 0, 0, 1, 0, 0, 0, 1, 0, 1), namely the optimal set of test points is [V1 , V5 , V9 , V11], which is consistent with the conclusion in the references [7].

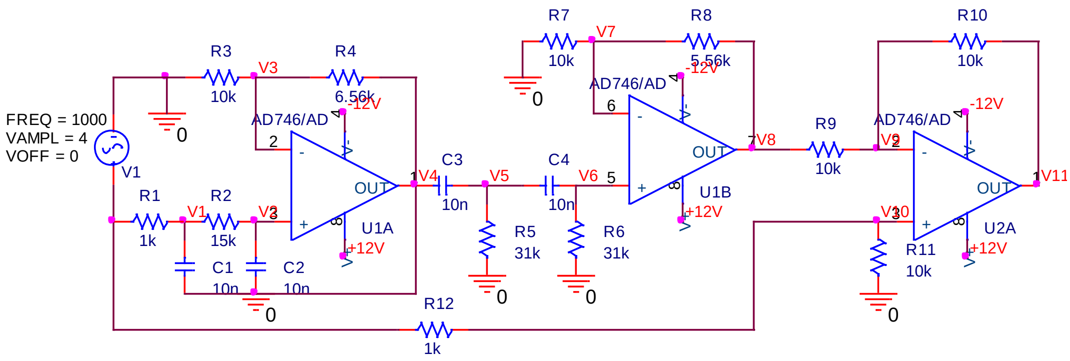

Fig. 1:The schematic diagram of filter circuit

Take a circuit in reference 7 as another instance, whose fault dictionary is indicated by Table 1.

Tab.1 The fault dictionary of filter circuit

Fault	Test										
	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}
S_0 (no fault)	3	2	2	3	3	3	4	4	1	1	1
S_1(R_1 open circuit)	0	0	0	0	0	0	0	0	1	1	7
S_2(R_1 short circuit)	3	2	2	3	4	3	4	4	1	1	0
S_3(R_2 open circuit)	1	0	0	0	0	0	0	0	1	1	7
S_4(R_2 short circuit)	2	3	3	4	6	5	6	6	1	1	2
S_5(R_3 open circuit)	1	1	1	1	1	1	1	1	1	1	5
S_6(R_4 open circuit)	0	0	0	2	3	2	3	3	1	1	8
S_7(R_5 open circuit)	3	2	2	3	5	4	5	5	1	1	4
S_8(R_5 short circuit)	3	2	2	3	6	6	7	7	1	1	6
S_9(R_6 open circuit)	3	2	2	3	2	0	0	0	1	1	7
S_{10}(R_6 short circuit)	3	2	2	3	3	3	4	2	1	1	4
S_{11}(R_7 open circuit)	3	2	2	3	3	2	0	8	5	1	8
S_{12}(R_7 short circuit)	3	2	2	3	3	2	2	8	4	1	8
S_{13}(R_8 open circuit)	3	2	2	3	3	3	4	4	1	1	0
S_{14}(R_9 open circuit)	3	2	2	3	3	3	4	4	2	1	8
S_{15}(R_9 short circuit)	3	2	2	3	3	3	4	4	3	1	8
SJ_{16}(R_{10} open circuit)	3	2	2	3	3	3	4	4	2	2	3
S_{17}(R_{11} open circuit)	3	2	2	3	3	3	4	4	0	0	1
S_{18}(R_{12} open circuit)	3	2	2	3	3	3	4	4	1	1	1

The dimension of this fault dictionary M is 16×13, and the binary vector represents the column selection of $X=(x_1, x_2, \dots, x_{13})$,$M$ namely the test points. Take EOR operation for every two rows of M to obtain the constraint matrix A, with the row number of 120 and column number of 13. Substitute the above conditions and go through BAB, and then obtain the solution X = (0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 0, 1, 0), namely the optimal set of test points is [V_7, V_8 ,V_9 , V_{10} and V_{12}], which is consistent with the conclusion in the references. Table 2 lists the performance comparison between the method in this paper and that in the references.

Tab.2 Performance comparison of test points optimization

Dictionary Scale	Optimal Test of Reference	Optimal Test of This Paper	Time Consumption of Reference (s)	Time Consumption of This Paper (s)
18×11	V_1 V_5 V_9 V_{11}	V_1 V_5 V_9 V_{11}	1.31	0.12
16×13	V_2 V_7 V_8 V_9 V_{12} V_3 V_7 V_8 V_9 V_{12} V_7 V_8 V_9 V_{10} V_{12}	V_7 V_8 V_9 V_{10} V_{12}	5.70	0.31

CONCLUSION

Take fuzzy set and fault dictionary as tools, and start from the constraint of fault isolation, to build an integer programming mathematical model for test point optimization and solve with branch and bound. The application of circuit simulation indicates that this method can realize the rapid optimization of test points on the premise of guaranteeing the demand of fault diagnosis.

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