A Network Decomposition Approach of Analog Circuit Based on Alternating Voltage

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ABSTRACT: In order to solve the difficult of fault diagnosis in large-scale analog circuits, a soft-fault diagnosis method is proposed, which is based on network decomposition, sensitivity analysis and support vector machine (SVM). Firstly, tear and isolate the target network with the use of AC and DC excitation. Then, prefer test node according to the concept of sub-network sensitivity and extract its information as fault feature after the Monte Carlo analysis and normalized processing. Finally, achieve fault network identification with the use of support vector machine classifier. The diagnosis principles and steps are described. Finally, the efficiency of the method is shown by practical examples comparing with the existing method, this approach which is suitable for tolerance and non-linear circuits, has smaller less computation, higher accuracy, and stronger engineering practicality.

1 INTRODUCTION

With the rapid development of integrated circuit technology, the size and complexity of analog circuits is increasing. Large-scale analog circuit fault diagnosis is becoming frontier and hot topics in circuit research. In recent years, neural network, wavelet analysis, optimization algorithm, search algorithm and other methods are applied to the diagnosis of large-scale circuits and achieved some results [1-7], but further detailed and perfect work are still necessary. Overall, the traditional network tear method build circuit equations in tearing point, and determine the fault network by cross-checking the calculated and measured values, which makes poor real-time, high computational, engineering realization difficult. Pattern recognition ideas in large-scale analog circuit fault diagnosis are also facing a series of problems, such as requires a lot of training samples, long training time, the number of species affect the classification accuracy rate and so on.

The literature [8] proposed a DC excitation sub-network tear method based on permutation theorem. The core idea of this method is replacing part circuits by applying DC voltages to identify faulty network. But the application of the DC excitation network tear method to determine the state of the sub-network requires certain preconditions: the test information can reflect the status of all components in the sub-network. But sometimes the use of DC excitation does not fulfill this requirement, such as capacitor open circuit fault and inductance short circuit fault.

To solve these problems, a network-tears method with the use of AC excitation. AC excitation is applied to make network replacement, in order to get richer system status information. The test point is preferred with use of sub-network sensitivity. Support vector machine is used for Monte Carlo analysis to identify fault sub-network, avoiding tolerance problem. Finally, through simulation experiments demonstrate the effectiveness of the method.

2 A NETWORK DECOMPOSITION APPROACH BASED ON ALTERNATING VOLTAGE

2.1 The fundamental of the method

The fundamental of the method is replacement theorem. firstly apply displacement voltage to isolate the target network, then take advantage of the fault feature comparison method to assure target sub-network status.

The literature [8] proposed a sub-network fault diagnosis method by applying DC voltage excitation source base on replacement theorem. At Pre-test time, the under test circuit network is divided into two sub-networks, and DC voltage are applied at the tear point. Then get the two sub-network internal test point response. When measured, apply the same DC voltage at the tear point, and get the two sub-network internal test point response. The fault
network can be located by comparing the measured response signal and Pre-test response signal at test points.

But the application of the DC excitation network tear method to determine the state of the sub-network requires certain preconditions: the test information can reflect the status of all components in the sub-network. But sometimes the use of DC excitation does not fulfill this requirement, such as capacitor open circuit fault and inductance short circuit fault.

For this reason, applying an alternating excitation signal on tear points are proposed in this paper. Because the alternative Theorem applies to DC network and exchange network, when replacing DC excitation to AC excitation the diagnostic method is still valid.

From another perspective, combining with calculus thought, AC excitation voltage can be equivalent to numerous DC excitation voltages at "time point". It can be seen as DC excitation accumulate on the timeline. "AC excitation tear" can be seen as "DC excitation tear" in numerous time point". Therefore the AC excitation can also achieve" torn "purposes.

The core ideas of network decomposition approach of analog circuit Based on alternating voltage is that isolating the impact of external circuits by applying displacement excitation. The main function of the excitation power: firstly, achieve equivalent sub-circuit isolation, reduce the complexity of the diagnosis; secondly, provide an excitation source for the test sub-circuit, and set the initial state of the circuit.

If the test circuit don’t have direction and initial state requirements, such as RLC circuit, according to the principles of diagnosis and tear described above, the circuit diagnosis can be completed.

But in the actual circuit, there are always some elements as transistors, FET, integrated chips, which have special requirements on conduction direction, quiescent point, and the power supply. The circuit cannot work and test points cannot produce a valid response if the conditions are not met. To solve the above problems, the solution is proposed as follow:

For circuits with active elements, apply corresponding external stimulus to ensure their normal work when making diagnosis; for circuit with FET, transistors and other components contained, the quiescent operating point and the directional requirements must be considered to ensure the circuit keep working.

2.2 The Tearing guideline

Every fault diagnosis method has its application conditions and scope. When using this AC torn approach, the follow guidelines should be complied with:

1) Tear point should be accessible;

2) In addition to tearing point, there is no other common point and branch network among sub-network after tearing;

3) After tearing there should not be parameter coupling phenomenon exists in each sub-network. for circuits with controlled sources, when tearing, controlled source and control source should be classified in the same sub-network;

4) The sub-network should contain accessible test points, and all element faults should be sensitized from the test points

5) The Excitation source must make the circuit work at normal operating range, and should not damage circuit components;

6) should be considered as much as possible to maintain the integrity of the tear each sub-network circuit structure and function of the respective sub-network contains several elements similar access tear point less in order to improve the diagnostic efficiency, ease next diagnosis.

The structure and function integrity of each sub-network after torn should be considered. Try to make each sub-network contains similar number elements and use less tear point to improve the diagnostic efficiency.

2.3 Test point optimization

Test point optimization is an important part in circuit fault diagnosis. The basic principle is as follow:

1. All element faults should be sensitized through test points' information.

2. The premise of ensuring 1, the test should take the minimum number test points;

3. Select the maximum element faults’ information test points when under the same conditions.

According to these principles, combined with the characteristics of the sub-network fault diagnosis method, the concept "sub-network sensitivity of test point" is proposed to distinction test points fault capability.

Definition 1: In circuit network F, Test point set N = {N1, N2, ..., Nn}, circuit elements set M = {M1, M2, ..., Mm}, the sensitivity matrix of circuit network F is as follow:

\[ S_F = \begin{bmatrix} S_{11} & \cdots & S_{1n} \\ \vdots & \ddots & \vdots \\ S_{m1} & \cdots & S_{mn} \end{bmatrix} \]  \hspace{1cm} (1)

Let the child be tested in the network F, N = {N1, N2, ..., Nn} and test points to be set, M = {M1, M2, ..., Mm} set of circuit elements, the sub-network F the sensitivity matrix

Test points N, relative sensitivity in network F can be expressed as

\[ S_F^{W_i} = \sum_{j=1}^{N} w_j S_{ij} \]  \hspace{1cm} (2)
i = 1, ..., n represents the number of test points; j = 1, ..., m represents the number of circuit elements; $S_{ij}$ represents normalized sensitivity, $w_j$ represents the right component value.

When selecting the test points, establish the sensitivity matrix of network at first. Then select the whole non-zero minimum sensitivity test points set as candidate set. Finally, determine the final test points by comparing network sensitivity of each candidate set.

3 FAULT TOLERANCE SUB-NETWORK RECOGNITION BASE ON SVM

The support vector machine (SVM) is a classification technique based on the structural risk minimization principle, which has strong generalization ability, small affected by noise, access to the global optimal solution, and unique advantage in the small samples and nonlinear problems.

The paper proposes a sub-network fault diagnosis method based on the exchange of torn, just judgment when using machine learning to identify the sub-network fault or not this duality problems and avoid errors more SVM classification problems caused by accumulation. This paper use SVM combined with sub-network diagnostics to judge fault network. The main diagnostic process has two steps:

3.1 Pre-test analysis

Analysis the circuit: Divide the sub-network and optimize the Test Points base on circuit topology and tear guidelines.

Collect the sample data: Build the test circuit in PSPICE software. Apply the corresponding excitation at tear point. Then make Monte Carlo analysis on no fault tolerance sub-network and get the response signal, as the original data samples.

Construct training sample: normalization process the original data samples to construct training set.

Establish SVM: Select the kernel function and penalty parameter (In this paper, RBF kernel function $\left(g(x,y) = \exp\left(-\gamma \|x-y\|^2\right)\right)$ is used, and PSO is used for parameter optimization) and establish the target network SVM,

Train SVM: Train SVM with training sample to obtain SVM classifier.

3.2 The actual test and analysis

Aiming at actual fault circuit, apply the same excitation on tear points and get the response parameters. Preprocess the data and input to the trained SVM classifier for pattern recognition. Judge sub-network state base on SVM output, and complete fault identification.

4 INSTANCE SIMULATION AND EXAMPLES OF SIMULATION RESULTS ANALYSIS

The paper show the basic diagnostic procedures in a two-step resistance capacitance coupled amplifier circuit experiment. Circuit parameters are shown in Figure 1, component tolerances are set to 5 percent range, points 1 to 12 are available.

Figure 1. Two-step resistance capacitance coupled amplifier circuit.

Different from ordinary RLC circuit, in this case the circuit contains transistors, the quiescent point problem exists. Quiescent point not only determines whether the circuit will produce distortion, but also affect the dynamic performance of the entire circuit. Therefore, when making the circuit fault diagnosis, it is necessary to ensure that the test circuit t and the simulation circuit have the same quiescent point. In this paper, "stable base voltage and isolation load" approach is used to ensure the quiescent point. Furthermore, since the amplifying circuit has directionality, in the diagnosis process, excitation signal set point should also be selected targeted

1) Pre-test

a. According to the basic principles of circuit torn, separate the circuit N to N1 and N2 along the dashed line (tear point 12, 3, 11)

b. Set the test circuit in PSPICE software. Through DC analysis, get quiescent point at point 6($V_6 = 1.583V$). Apply $V_{63} = 10V, V_{64} = 1.583V$ at point 6 and point12. Compare each sub-network accessible point voltage before and after apply excitation (as shown in Table 2), finding own the same voltage, which indicate that the same quiescent point can be got through apply excitation without affecting the circuit operation.

c. the circuit sensitivity analysis, establish the sensitivity matrix of sub-network, and select point 3 as N1 test point after comparing sub-network sensitivity of each point.

d. Setting circuit element tolerances: resistor tolerance take 10%, capacitance tolerance takes 5%. Select the test point voltage maximum as fault characteristics. For N1, applying an excitation signal at point 1, with 300 times Monte Carlo analysis, no
fault state test point response signal is obtained, as the original sample.

<table>
<thead>
<tr>
<th>V_1</th>
<th>V_2</th>
<th>V_3</th>
<th>V_4</th>
<th>V_5</th>
</tr>
</thead>
<tbody>
<tr>
<td>No fault</td>
<td>0</td>
<td>1.583</td>
<td>5.769</td>
<td>856.3</td>
</tr>
<tr>
<td>After tearing</td>
<td>0</td>
<td>1.583</td>
<td>5.769</td>
<td>856.3</td>
</tr>
</tbody>
</table>

2) Post-test
For sub-network N1, Apply $V_{34} = 10V, V_{34} = 1.583V$ at point 3 and point 4. Apply $V_t = 5\sqrt{2} \times 10^{-3} \sin(2000\pi t)$ V at point 1 as excitation signal. Obtain the corresponding parameter at point 3 as a sample to be tested. Then train SVM classifier for pattern recognition. Make every element in the sub-network N1 changes the parameters as follows: 0%, 1%, 10%, 20%, 50%, 100%, 150%, 200%, 500%, 1000%. Comparing the recognition result, the accuracy of identify faulty network N1 was 97.14%.

The above experiments show that the proposed method can quickly and accurately identify target sub-network fault conditions. Compared with the literature [1, 2, 9], The method solves the problem of fault-sensitized dynamic element and improve the scope and efficiency of diagnosis. Compared with the literature [4, 5] method, the method eliminate the interaction between the sub-networks, reduce the complexity of the diagnosis, have a small amount of calculation.

It should be noted that, although this embodiment is directed to a single fault conditions, the method is also applicable to multiple fault diagnosis.

5 CONCLUSION
A network decomposition approach of analog circuit based on alternating voltage is put forward in this paper. Through applying replacement voltage, the method isolates the fault propagation path, excluding the impact between the cascade circuits; reduce the failure combination, reducing the complexity of the diagnosis.

Apply AC excitation achieving network replacement based on DC excitation, which provides more extensive system status information, making the diagnosis more accurate and effective. Use SVM for pattern recognition, solving the "curse of dimensionality" problem. The method which is adapted for linear and nonlinear circuits has a small amount of calculation. It can also solve tolerance and soft fault problem, and is easy to engineering practice. Simulation results show that the method has higher fault recognition accuracy. In addition to these advantages, there are also some shortcomings. The method need some accessible circuit points for circuit tearing and fault information extracting. External stimulus is also needed which adds some complexity degree. Facing these problems, boundary-scan technology [10] combined with BIT system design is a kind of solution, which solve the test isolation, excitation applying and respond capturing problem.

REFERENCES