

A method for minimum node selection in diagnostics of analog systems

Adrian Bilski¹, Jacek Wojciechowski²

¹ Institute of Radioelectronics, Warsaw University of Technology, Nowowiejska 15/19, 00-665 Warsaw, Poland and Faculty of Applied Informatics and Mathematics, Warsaw University of Life Sciences, Nowoursynowska 159, 02-776 Warsaw, blindman26@o2.pl

² Institute of Radioelectronics, Warsaw University of Technology, Nowowiejska 15/19, 00-665 Warsaw, Poland, jwojc@ire.pw.edu.pl

Abstract- The aim of this work is to introduce a strategy for finding minimal set of test nodes for diagnostics of complex analog systems with single parametric faults, using SVM classifier as a fault locator. The results of diagnostics of a low-pass filter using *taboo* search and GA algorithms as node selectors in conjunction with SVM fault classifier are presented.

Keywords - Complex analog systems, Support Vector Machine, taboo search, genetic algorithm, parametric fault detection.

I. Introduction

Continuously increasing number of elements in analog systems makes their testability and diagnostics difficult. In case of systems that work on high frequencies or the data acquisition systems, it is necessary to conduct a separate diagnostic of the analog and digital parts. While the diagnostics of digital circuits has already defined testing procedures, no such method has been formulated for analog or mixed systems. The testability of digital, analog and mixed circuits is crucial to decrease the costs of production of the modern electronics [1,2]. The fault diagnostics in analog systems is subsequently complicated because of the element tolerances.

Analog system can be perceived as complex in terms of its structure, if the number of parameters of the system is large enough (e.g. more than 20). The information about the systems behavior is acquired from signals, therefore the lesser number of parameters, the easier the diagnostic process. The aim of diagnostic is the determination whether the analyzed analog System Under Test (SUT) works properly, based on the analysis of the observed signals, acquired from the accessible or partially accessible nodes. This analysis exploits measurable information from the systems signals (usually described by real numbers – the coordinates of characteristic points) by determining how large is their deviation from the nominal values.

A proper selection of characteristic points creates the possibility of both detection and diagnosis of a fault. Through parametric simulation it is possible to acquire information on the behavior of the complex analog system while the values of certain systems parameters are subject to change. Such method is similar to the limit values method, which can be brought down to constant checking whether the selected characteristic point V belongs to the set of values ensuring the proper work of the system (1).

$$V_{min} \leq V(t) \leq V_{max} \quad (1)$$

Though general methods for effective diagnostics of complex analog systems do not exist, there have been some attempts in creating them [3-5]. One of the more interesting is the decomposition method [6,7], based on creating test Kirchhoff's current equations at the circuit decomposition nodes. However a significant calculation time of such a method limits the size of possible circuits and such methods are now considered to be obsolete with the advent of modern heuristic methods.

The SVM classification algorithm has already been used in diagnostic studies conducted on the electronic analog systems [4, 5, 11, 12]. Although this categorization tool is enough versatile to utilize it on the data of various complexity, the process of optimal kernel selection and its parameters needs to be conducted each time a new system is analyzed [13]. It also provides sufficient classification results in noisy conditions. The systems presented in [5,11,12] are described by a small number of parameters (from 7-element up to 16-element

systems). The SVM presented there are used for classification purposes in fault detection. These circuits are of significantly lesser complexity than the system analyzed in this work.

The aim of the research described in this paper is a formulation of an algorithm for selection of minimum number of nodes in a complex analog system, that would provide sufficient accuracy of diagnostics. Two algorithms are proposed here – *taboo* search (2) and the GA algorithm (3), while SVM has been used as a fault classifier.

This paper is organized as follows. The description of data processing method and the minimal node selection algorithms are in the section II. Section III contains the illustrative example, i.e. the 52-element low pass filter and experimental results. In section IV conclusions are included.

II. Diagnostic principles

The focus of this paper is the single parametric faults detection. Information about the systems behavior is acquired from the output signals provided by the parametric simulation (Fig.1) of faulty and nominal systems. Faults of each element are simulated by eight examples with different fault intensity. Some components require greater deviation from nominal value than others in order for the change to be visible in the systems output signal. The measure of effect on the SUT output is important in the selection of parameter fault values. The particular classes must be significantly unique for the SVM to conduct proper fault classification. The uniqueness of these categories have an impact on the size of datasets provided for the SVM. The examples for the testing dataset were selected randomly with the uniform probability distribution. The diagnostic quality was measured as the percentage of the correctly classified examples.

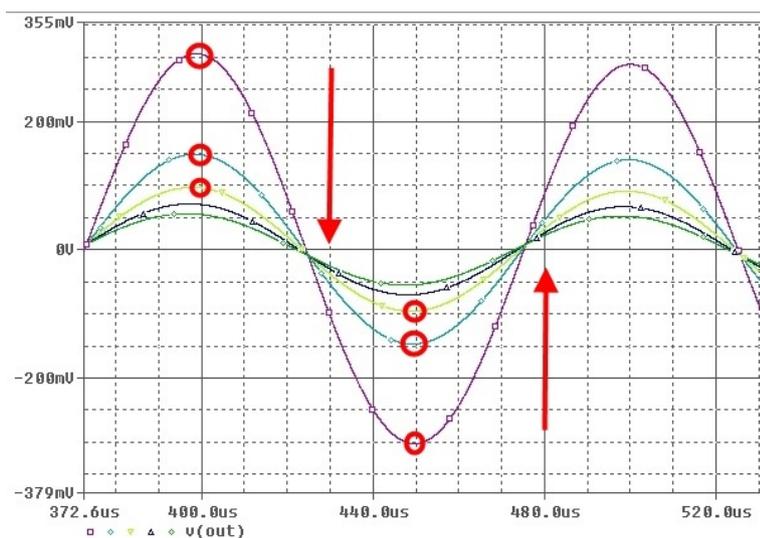


Figure 1. Example shows how the output signal of the 52-element low-pass filter changes based on the increase of the R2 value in the range 100 - 900 Ohms. The characteristic points are also indicated.

The diagnostics were conducted in time and frequency domains. In case of time domain the characteristic points were the values of the first maximum and first minimum value of the output signal after it stabilizes and the time instants needed to reach them. In case of frequency domain, the 3db-frequency was taken into consideration. These characteristic points were chosen for the diagnostic tasks because they can provide the most information about the system behavior during a parametric simulation. The element tolerances are included in the problem. The values of the parameters are allowed to randomly change in the interval $\pm t\%$ around the nominal value. It is assumed that the system works according to the specification if the parameters values do not exceed the tolerances (a worst case scenario).

The SVM toolbox used in this research was the Steve Gunn's toolbox. Its kernel parameters were set according to [8]. The tested analog system was based on a 52-element low-pass filter, which has already been the subject of diagnostic studies in various publications [4,6], but the methods used in these analysis were unsatisfactory. Two algorithms of discrete optimization were applied for the node selection – *taboo* search and genetic (GA). The reason for their application in the process of node selection is the fact that they produce partial solutions in each iteration. This allows the supervisor of the algorithm to assess the quality of the provided solution each time one is produced.

The target function of the *taboo* algorithm (1) is the quotient of classification efficiency (*classification_efficiency*) and diagnostic time in seconds (*classification_time*).

$$t_function = \frac{classification_efficiency}{classification_time} \quad (2)$$

Classification efficiency is a quotient of the number of the correctly categorized examples (positive) and the number of all examples from the training or testing datasets (*examples*) (3).

$$classification_efficiency = \frac{positive}{examples} \quad (3)$$

The algorithm works under the assumption, that all nodes in the analyzed system are accessible and can be at any given moment excited and signals read from. A successful solution presents nodes that should be excited and measured to get better results than input-output analysis only [1], but does that in the shortest possible time. Such information can be then used by the designer of the analog system to make the diagnostics easier and less costly.

The *taboo* node selection algorithm is iterative and it works as follows [10]:

```

Procedure TabooSearch
Solution=best=random_solution
Taboo_list:=0
  Begin
  While not (stop condition) do
  Begin
    Evaluate best
    Solution=select(neighbors(solution),taboo_list)
    Taboo_list=update_taboo(solution,t taboo_list)
    Evaluate Solution
    If (evaluate(best)<evaluate(solution))
      Best=solution
  End
  End
End
  
```

Solution vectors are binary of the length equal to the number of nodes in the analyzed system: value 1 is assigned to the node selected for testing. Initial solution vector is created randomly. Having determined which nodes to excite in the simulation, the SVM performs the fault classification procedure. *Taboo* element is randomly selected from the nodes that are still not *taboo*. Its label is changed to an opposite. This element will be *taboo* for a number of iterations depending on the number of nodes in the analyzed system. A new solution is a different node configuration. The stop condition for the *taboo* search algorithm was reaching the 100th generated solution.

The algorithm operates on the example sets that were already created for each node before the simulation started. This means that the algorithm does not conduct parametric simulation for each node each time a new solution is generated. Such an approach significantly speeds up the algorithm. It should also be noted that the efficiency of a *taboo* search depends mainly on generated solutions, which are created randomly. In order to limit the number of generated solutions, the ones that include the node situated near the power supply can be eliminated, because it is assumed that the systems faulty behavior can't be caused by a faulty power supply.

The GA node selection algorithm adopted according to the scheme proposed by J. Holland [9]:

Procedure Basic GA

Begin

T:=0

Intialization of P0

Evaluation of P0

While not (stop condition) do

Begin

Tt := reproduction of Pt

Ot:= crossover and mutation of Tt

Evaluation of Ot

Pt+1:=Ot

T:=t+1

End

End

The initial population P0 is selected randomly. Each member of the population is a binary vector having the same form as in the previous algorithm. In this exercise each population consists of 60 solution vectors. It is a sufficient number to maintain diversity in the population while maintaining the algorithms functionality. During the estimation of a population, a particular solution is chosen to be reproduced based on the fault classification estimation, provided by the SVM classifier (3). Genotypes of the selected specimen are submitted to the evolutionary operations, with probability parameters of crossingover (pc) of 0.7 and mutation (pm) of 0.01. These are the values that provide the most variety in the reproduction process of populations, with the crossing over operation more significant in these tasks. The method of specimen selection used in these studies is the proportional reproduction, described with (4).

$$p_r(x) = \frac{\varphi(x)}{\sum_{y \in P_t} \varphi(y)} \quad (4)$$

where x is a single specimen (solution vector), while $\varphi(x)$ is its fit value. GA stop condition was generation of the 30th population.

III. Experimental results

The system in Fig. 2 is a 52-element fourth-order elliptic active low-pass filter with 19 nodes. It consists of two positive feedback loops and 8 operational amplifiers modeled by a controlled source (VCCS) and the input and output resistances. The faults modeled in these amplifiers provide the information about which VCCS is corrupted. The system has been excited by a 10mA current source of a 10kHz frequency [6], [8]. The optimal selection of nodes is given in Tables 2 and 3. The best diagnostics results can be achieved by using SVM with rbf kernel functions. The parameters of the simulation are presented in Table 1.

Table 1. Simulation parameters for the 52-element low-pass filter diagnosis.

Simulation parameter	Parameter value
Rbf kernel parameter	0.000039-0.000096
Erbf kernel parameter	0.00108-0.00207
Polynomial kernel parameter	33-103 degree
Size of the learning dataset (number of examples)	416
Size of the testing dataset (number of examples)	208

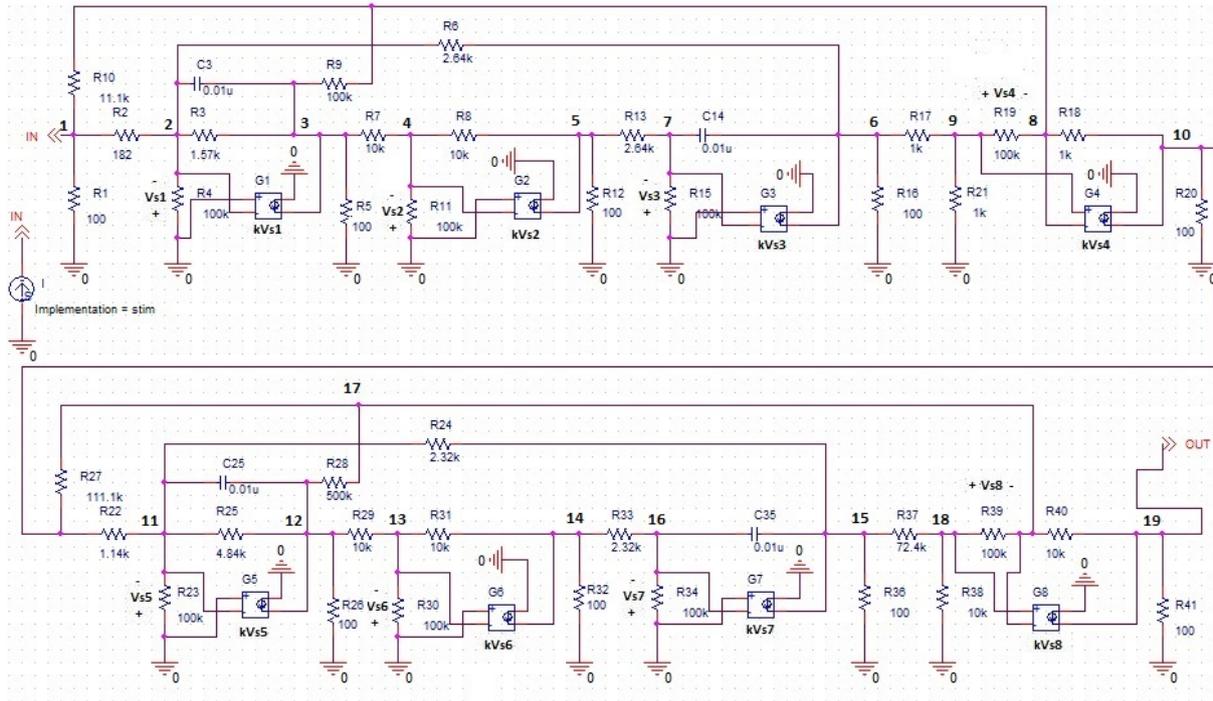


Figure 2. A 52-element low-pass active filter with 19 accessible nodes modeled in Spice.

Tab. 2: The best node selection for a 52-element low-pass filter, provided by the GA simulation.

Node number/ kernel type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Efficiency	Target (min)
Rbf/ Erbf	0	1	0	1	0	1	0	1	0	0	1	0	1	0	1	0	0	1	0	78%	3,931e-4
	0	0	1	0	1	0	1	0	1	0	0	1	0	1	0	1	0	1	0		
Poly	0	1	0	1	0	1	0	1	0	0	1	0	1	0	1	0	0	1	0	70%	3,528e-4

Nodes 2 and 3, 4 and 5, 6 and 7, 9 and 10, 13 and 14, 15 and 16, 18 and 19 can be excited interchangeably, because that is less significant to the diagnostic process. The inclusion of the output node to solutions presented in Tables 2 and 3 increases the classification efficiency of the parametric fault in the low-pass filter system to 82%.

Tab. 3: The best node solution for a 52-element low-pass filter, provided by the *taboo* search simulation.

Node number/ kernel type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Efficiency	Target (sec)
Rbf/ Erbf	0	1	0	1	0	1	0	1	0	0	1	0	1	0	1	0	0	1	0	78%	2,65
	0	0	1	0	1	0	1	0	1	0	0	1	0	1	0	1	0	1	0		
Poly	0	1	0	1	0	1	0	1	0	0	1	0	1	0	1	0	0	1	0	70%	2,38

IV. Conclusions

This work shows an increase in parametric fault classification efficiency compared to [1]. The minimal number of nodes needed to improve the fault classification efficiency of the 52-element low-pass filter compared to input-output only analysis is 40% of all the nodes in the case where the output nodes is omitted. In the case of the presented system it was 9 out of 19 nodes. The training of the classifier consisting of 2944 examples lasted

1984 minutes (around 33.1 hours). In case of simulation with the inclusion of the output node, the desirable fault classification efficiency could be achieved within around 23-26% of the total number of system nodes. It can be perceived as a satisfying result, considering the fact that parametric faults in complex analog systems of over 50 parameters are considered.

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