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A Novel Method for Detecting Parametric Faults in Analog Circuits using Fuzzy Logic

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Abstract*: The demand for testability analysis of analog circuits has been increased in recent years. The fault detection and fault classification method is important in detecting the parametric faults of the circuit. In this paper, Simulation Before Test (SBT) is considered as a basic mechanism for detecting the parametric faults.. The circuit Under Test (CUT) used is Sallen-Key bandpass filter. Transfer function of the CUT is used for fault detection by locating the poles and Zeros of the transfer function. Fuzzy logic is used for fault classification.

Keywords: SBT, CUT and fuzzy logic.

I. INTRODUCTION

In recent years fault diagnosis in electronic circuits has become an active research area because the reliability of the product is measured by testing and validation [1]. It is found that a significant cost of the product amounts is spend for testing and mostly testing is done only in the analog part of the circuit. It is observed from recent studies which have shown different fault identification models upto 50% variation in the component values but still new approaches are needed below 50 %.[2] Automated fault detection technique improves the efficiency of the fault detection in the system.. The two different simulation methods used in parametric fault detection are Simulation Before Test (SBT) and Simulation After Test (SAT)[7].In Simulation Before Test by injecting the faults in the circuit fault dictionary is created and fault detection is done by a soft computing method. Artificial Intelligence and reasoning methods are the two different methods used in Simulation After Test. Nowadays soft computing technique plays a major role in various fields of Engineering. Intelligent algorithms were used to find an optimum solution for the problem. Soft computing techniques like fuzzy logic, Neural network and Genetic Algorithm are oftenly used for these types of problems[1]. Fuzzy logic is one of the simplest and effective method which suits for many problems[5]. Especially when there is no mathematical relationship between the input and output.

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II. METHODOLOGY

A. Fault Detection

Transfer function is considered as the key factor which is used to create the fault dictionary. For any circuit the location of poles depends on the transfer function of the circuit. Changes in the values of the parameters such as Resistors and Capacitors will affect the transfer function which leads to the change on the location of the poles.

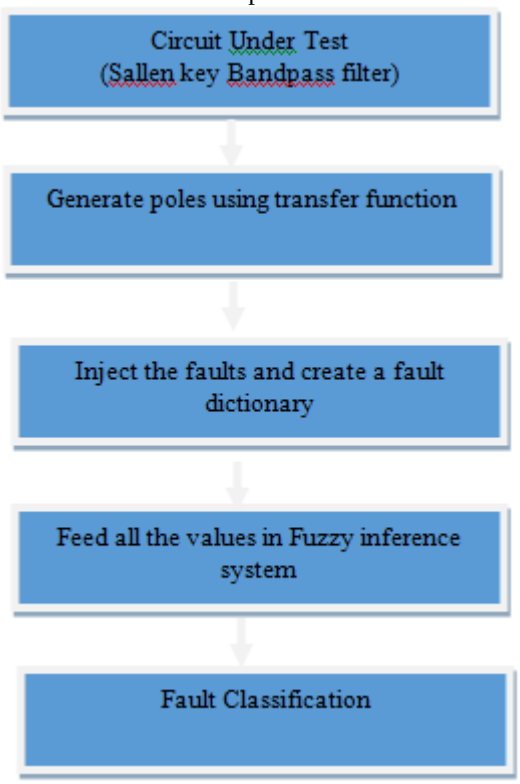

Fig 1: Flow Diagram

The above flow diagram shows the complete steps involved in this method of finding the parametric faults using fuzzy logic. Fault dictionary has to be created by injecting the faults. In order to create the fault dictionary, transfer function of the circuit is used to extract the poles and zeros and fuzzy logic is used for fault classification and fault detection. Fault dictionary is created by injecting the faults in the circuit and generating the corresponding poles location through transfer function Fault model is defined by the faults with respect to the components present in the filter and its fault range. For example, R1+10%,R1+20%,here for each component the fault model ranges from -50% to +50% from its original value.

The step size for each variation is 10.

Table 1 : Fault Dictionary

FAULT CONDITION OF THE CUT	REAL PART (IP-MSF1)	IMAGINARY PART (IP-MSF2)	FAULT INDEX (OP-MSF 1)
Fault free	0.1931	1.5326	I
R1-50%	-0.0113	0.1193	II
R1-40%	-0.0428	0.85971	III
R1-40%	-0.0578	0.62161	IV
R1-30%	-0.0413	0.44305	V
R1-10%	0.0114	0.30416	VI
R1+10%	0.0909	0.19305	VII
R1+20%	0.1762	1.0214	VIII
R1+30%	0.2416	1.26385	IX
R1+40%	0.266	2.6385	X
R1+50%	0.2416	3.711	XI
R2-50%	0.1762	1.0896	XII
R2-40%	0.0909	1.40286	XIII
R2-30%	0.0115	1.8008	XIV
R2-20%	-0.0412	1.5896	XV
R2-10%	-0.0414	1.5432	XVI
R2+10%	-0.0577	1.4352	XVII
R2+20%	-0.0425	1.3985	XVIII
R2+30%	-0.0112	1.3726	XIX
R2+40%	-0.0105	1.3015	XX
R2+50%	-0.005	1.2015	XXI

The above fault dictionary is a sample fault dictionary which is created using only Resistors R1 and R2. Similarly by considering all the Resistors and Capacitors in a circuit, a complete fault dictionary can be created.

B. Pole Zero Plot

Pole-Zero Plot is created by using the MATLAB tool. In order to create a pole zero plot the transfer function of the Circuit is to be found. The pole and Zeros value is a complex a number. Fig 2 shows the Pole-zero plot for the various faults created in the fault dictionary.

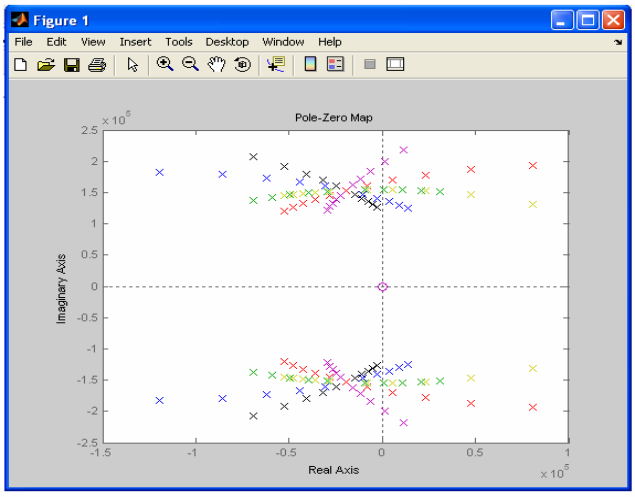

Fig 2 : Pole-Zero Plot

B. Sallen key Bandpass filter

Sallen-key is a type of Voltage-Controlled Voltage Source (VCVS) topology. It is chosen as Circuit Under Test (CUT) because of its properties such as High input impedance and easily selectable gain. A SK (Sallen-Key) filter has a slight variation compared to a VCVS filter with respect to its gain. A SK filter is a variation on a VCVS filter that uses a unity-gain amplifier. The CUT used in this paper is a second order Sallen key band pass filter.

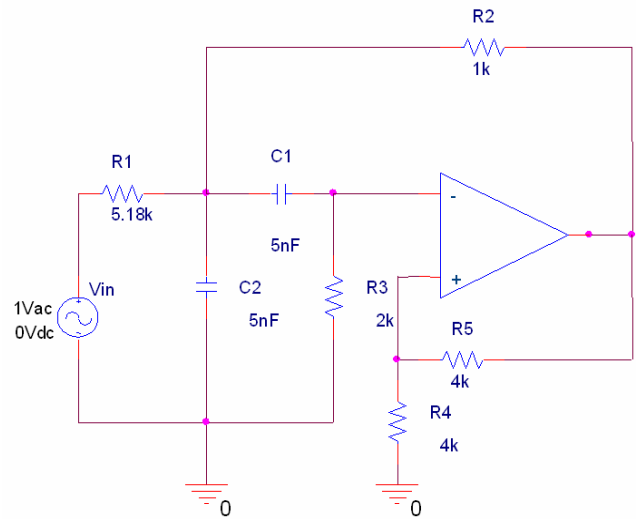

Fig 3: Sallen key Band pass filter

The transfer function of the filter is

$$G(S) = S\,A0G1G2 \;/\; \{S2C1C2 + S(G3C1 + G3C2 + G1C1 + C1G2(1A0)) + G3(G1 + G)\}$$

C. Fuzzy Logic

Fault detection is done by using Fuzzy logic. In Recent years application of fuzzy logic is increased significantly. Fuzzy logic is a multi-valued logic with unsharp boundaries.

D. Fuzzy inference system

Fuzzy inference system has a very good reputation in various fields such as data classification, expert system, decision analysis etc…The process of mapping the input to its output is done by fuzzy inference system, then this mapping give the basic idea to make the decisions. The fuzzy inference system (FIS) classifies the fault in an effective way.

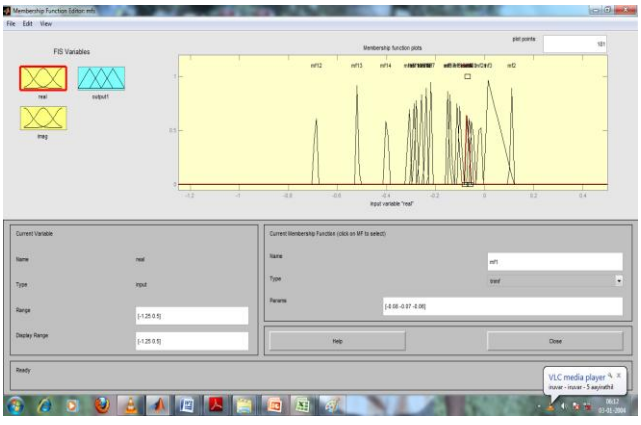

Fig 4 : Fuzzy inference system

The values stored in fault dictionary is entered in FIS. The pole values are complex numbers, so two input variables is needed to enter the pole values. The total number of membership function needed is equal to the total number of values present in the fault dictionary. While entering real and imaginary part of the poles, we have to set the range in FIS editor. Which should cover all the values present in the fault dictionary. An example of an Input MSF (Membership function) is as follows.

"If (real part lies in the range [-0.20 -0.19 -0.18]) and (imaginary part lies in the range [1.52 1.53 1.54])then (the range of output1 is [0.9 to 1.1])".

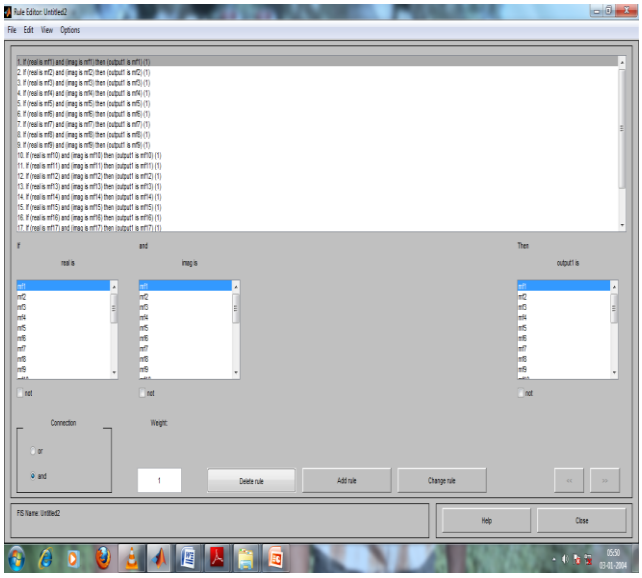

Fig 5 : Fuzzy Rule constructor

E. Defuzzification

The Centroid of Area (COA) defuzzifier generates the output value 0.19 which is equal to the fault index 1.By having a complete fault dictionary, we can enter all the values of real and imaginary part as membership function 1 and 2 so that the defuzzifier generates corresponding fault index value whenever a match is found. while entering the range for fault index in the FIS editor, the range should be in such a way that in should cover all the fault model present in the fault dictionary.

F. Validation

Validation is done by entering any value from the fault dictionary. If one want to check for R1-50%, then its value should be entered in fuzzy Rule viewer which checks the member ship function and give its corresponding fault index value. This can be verified by comparing the output of the FIS ruler with the fault dictionary

G. Rule viewer

Once the rule for all the pole s is constructed then using rule viewer the output is verified by giving the input ie. Real and imaginary value of any one of the pole in the fault dictionary and the rule viewer gives its corresponding fault index value.

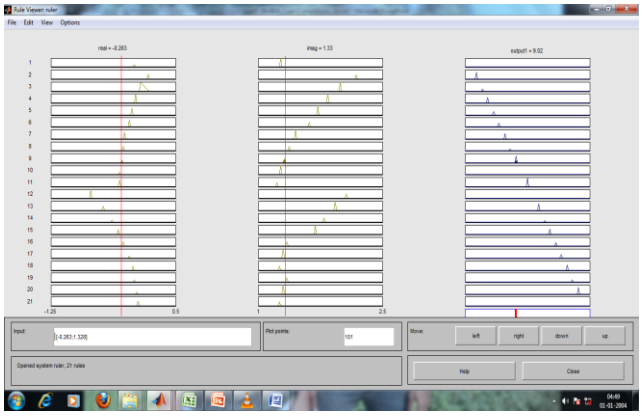

Fig 6: Fuzzy Rule Viewer

III. RESULTS AND DISCUSSION

In this paper fuzzy logic is used for fault detection. Table 1 shows the sample fault dictionary which is created by changing the Resistor values. The values of Real and Imaginary part tin Table 1 is entered in FIS as input Membership function. Fault index value in Table 1 is entered as an output value. Fig 5 Fuzzy Rule constructor is used to frame the rules using the input and output membership functions. Fig 6 Fuzzy Rule viewer is used to see the output where the values present in fault dictionary is entered and it displays the corresponding fault index value by which one can identify which component's value is changed and upto what percentage it is changed from its original value.

Table 2 : Sample output

IP-MSF 1	IP-MSF2	OP-MSF3	Fault Condition
0.2660	2.6385	10	R1+40%
-0.0412	1.5896	15	R2-20%
-0.042	0.8597	3	R1-40%
0.0909	0.1930	7	R1+10%
0.2416	1.2638	9	R1+30%

In table 2 0.2660 and 2.6385 are the two input membership function from the fault dictionary which is given to the fuzzy rule viewer of Fig 6. In FIS, as a result of Defuzzification it traces the output membership function of 10 as output. Then by searching the corresponding value in fault dictionary its fault condition is identified as R1+40%. The above method is applicable for all the data present in fault dictionary.

IV. CONCLUSION

In this paper poles is used as a parameter to detect the fault in the circuit. The pole value is extracted from the transfer function of the CUT. Similarly parameters like frequency and Gain can be used to create fault dictionary. Fuzzy logic is used for fault classification which is a simplest and effective method suited for this problem.

Various soft computing techniques and machine learning methods can be used in the future for this problem.

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