



Multi Frequency Approach to Analog Fault Diagnosis using Pole Sensitivity Analysis

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ABSTRACT: In this paper an efficient algorithm using multi-frequency approach has been applied to fault diagnosis of analog electronic circuits using Pole Sensitivity analysis. Here after the application of the multi frequency approach to the pole sensitivity analysis the results show that the fault diagnosis of the circuit has increased. This has been proved by using a Band Pass Filter.

Keywords: *Pole Sensitivity, Zero Sensitivity, Multi frequency, Fault Diagnosis, Ambiguity table.*



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1. INTRODUCTION



The increasing complexity of the System-on-chip (SOC) makes it very important for the accuracy and consistency in timing analysis and clock distribution. The importance of the analog circuits is increasing, the main reason is that the digital systems need analog circuits to interface to the real world which is analog in nature. Analog circuits have in fact expanded with the digital circuits into new applications. Analog circuits occupy only a small fraction of the total area of an integrated circuit. But the performance of analog circuits is very critical in the performance of the system. Analog integrated circuit fault diagnosis is thus very important.

Analog Fault Diagnosis has been of immense research interest for the past three decades and continues to sustain the same zeal even today. The main challenges today in analog fault diagnosis are to design universally accepted fault models, cost effective, faster and accurate diagnosis of faults. Importantly all this is desired even in the presence of inherent characteristics of analog circuits like tolerances, non-linearity and in-accessible test nodes etc.

S.P. Venu Madhava Rao, N.S.C. Babu and K.Lal Kishore [1] have proposed a novel node-frequency approach in analog fault diagnosis which resulted in more faults being diagnosed. In [2] a circuit has been designed and developed using reconfigurable architecture to diagnose faults in analog circuits. N.S.C. Babu, S.P. Venu Madhava Rao and others in [3] proposed an efficient algorithm that improves the existing multi-frequency approach in diagnosing more faults at a faster rate.

T.N. Trick and Y.Li proposed a new first order sensitivity fault isolation algorithm [4]. The independence of the sensitivity vectors indicates that the test points are capable of identifying faults. The degree of the testability of the circuit under test is determined by the rank of the sensitivity matrix of the columns.

L.Rapisarda and R. DeCarlo [5] used component connection mode in the development of multi frequency problem. This method made the solution process simple, as the equations now have a fixed polynomial order which is generally quadratic. The developed method also includes a test for diagnosability. John W. Bandler and others [6] made an exhaustive and comprehensive review of the fault location techniques in analog electronic circuits. The four main approaches discussed in this paper are fault dictionary approach, parameter identification approach, the fault verification approach and the approximation approach. A method is used which expands the harmonic balance technique from non-linear simulation to non-linear adjoint sensitivity analysis [7]. The hierarchical approach is used to compute sensitivity analysis and calculates responses in any sub circuit in the hierarchy. Another multi frequency approach deals with the optimum selection of test points and frequencies [8]. The method presented is based on the large change sensitivity analysis and the deviation of the element values is taken from zero to infinity. Symbolic analysis is used in the calculation of the column rank of the sensitivity matrix [9]. Baoru et. al in [10] proposed a tolerance analog circuit hard and soft fault diagnosis method based on adoptive learning rate and additional momentum algorithm BP neural network.

2. POLE ZERO ANALYSIS

The Numerator and Denominator polynomials of the Transfer function are written as given in equation (1).

$$H(s) = \frac{N(s)}{D(s)} = K_m \frac{(s-z_1)(s-z_2)\dots(s-z_m)}{(s-p_1)(s-p_2)\dots(s-p_n)} \dots \dots (1)$$

Where $K_m = a_m/b_n$, s is the complex frequency and is equal to $s = \sigma + j\omega$. The roots Z_i of the numerator polynomial $N(s)$ ($N(s) = 0$) are called Zeros of the transfer function and the roots of the denominator polynomial $D(s)$ ($D(s) = 0$) are called Poles of the Transfer function, m and n are the numbers of the Zeros and Poles respectively. The coefficients of the numerator and denominator polynomials are real, therefore the Poles and Zeros must be either be real or appear in complex conjugate pairs. The Poles of the network depend only on the network structure and are independent of the input excitation. Whereas the Zeros of the network depend on the place to which the source is applied and also depend on the point where the output is measured.

The Poles and Zeros of the linear circuit together with the real constant K_m or K_0 completely determine the transfer function as a function of the complex frequency s . The transfer function is normally represented by the Pole and Zero diagram of the complex frequency s , whose axis represents the real and imaginary parts of the complex variable s .

3. POLE SENSITIVITY ANALYSIS

In [11] a method based on sensitivity investigation of the test characteristics in the frequency domain has been presented.. The effect of parameter changes on performance specifications caused by the deviation of the manufacturing process can be determined by using the sensitivity analysis in [12].

To test analog circuits lot of information has to be provided to test engineers. For fault diagnosis of analog circuits, information like number of testable and non-testable components, ambiguity groups etc. are needed. The sensitivity analysis based on a first order approximation provides the variation of a circuit's response w.r.t parameter variations.

There are two forms of sensitivity- normalized differential sensitivity and normalized incremental sensitivity. The normalized differential sensitivity is given by the equation (2) and the incremental differential sensitivity is calculated using (3).

$$S_{h_i}^{T_j} = \frac{h_i}{T_j} \frac{\partial T_j}{\partial h_i} \dots \dots \dots (2)$$

$$\rho_{h_i}^{T_j} = \frac{h_i \Delta T_j}{T_i \Delta h_i} \dots \dots \dots (3)$$

In this paper Pole-Zero analysis as proposed in [11] has been used in the fault diagnosis of analog circuits which enables the time and frequency responses to be calculated easily. The calculation of Pole –Zero sensitivity analysis has wide range of applications:

- Provides fundamental information about the system stability
- Allows the designers to follow the direction and magnitude changes caused by the changes in element values
- Helps in extracting the behavioral model of the analog circuits
- Helps in calculation of transient and AC sensitivities

In this paper Pole-Sensitivity has been used in association with the Multi-Frequency approach to diagnose faults along with other known methods. This has increased the number of faults that are diagnosed successfully.

4. ALGORITHM 1

Step 1: The circuit is modeled using the transfer function in S- Domain.

Step 2: The Poles and Zeros of the circuit are determined form the transfer function calculated in Step 1.

Step 3: Using Adjoint method the Pole sensitivity with respect to the circuit elements is calculated.

Step 4: Ambiguity groups are formed from the pole sensitivities.

Step 5: If the ambiguity group from step 4, consists of more than one fault signature in a group, Multi frequency approach is used to isolate faults.

Example 1: Band Pass Filter

The Figure 1 shows a simple BP filter, which has been taken for analysis.

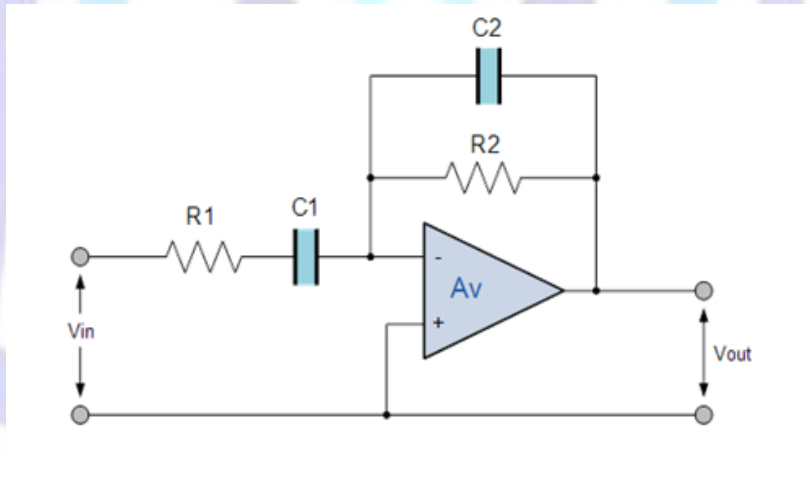


Figure 1: Band Pass Filter

In this filter $R_1 = 10K\Omega$, $R_2 = 20K\Omega$, C_1 and $C_2 = 11.2$ nF. The transfer function of this circuit is given by:

$$H(s) = \frac{-R_2 C_1 S}{S^2 R_1 C_1 R_2 C_2 + S(R_1 C_1 + R_2 C_2) + 1} \dots \dots (4)$$

The sensitivity of the poles under nominal case (without faults) is calculated using equation (2) and (3) and the results are tabulated in Table 1.

Table 1: Sensitivity of Poles –Nominal Case

Component	S_h^{P1}	S_h^{P2}
R ₁	-1.000	0
R ₂	0	-0.9612
C ₁	-1.000	0
C ₂	0	-0.9612

Now the BP filter has been induced with eight different faults. The Table 2 gives the different types of faults that are assumed to be present in the circuit.



Table 2: Fault Types

S.No	Type of Fault	Name
1	$R_1+10\%$	F_1
2	$R_1-10\%$	F_2
3	$R_2+10\%$	F_3
4	$R_2-10\%$	F_4
5	$C_1+10\%$	F_5
6	$C_1-10\%$	F_6
7	$C_2+10\%$	F_7
8	$C_2-10\%$	F_8

The sensitivity of Poles is calculated for the circuit under fault condition and the results are shown in Table 3.

Table 3: Sensitivity of Poles –Faulty Case

Faults	S_h^{P1}	S_h^{P2}
F_1	-0.9091	0
F_2	-1.1111	0
F_3	0	-0.8739
F_4	0	-1.0680
F_5	-0.9091	0
F_6	-1.1111	0
F_7	0	-0.8739
F_8	0	-1.0680

As seen from this Table 3, the Faults are not isolated by this method. Also it has been found that the fault pairs F_1F_5 , F_2F_6 , F_3F_7 and F_4F_8 have the same fault signatures. These fault pairs form the ambiguity table shown in Table 4.

Table 4: Ambiguity Table

Type	Gr 1	Gr 2	Gr 3	Gr 4
Faults	F_2F_6	F_3F_7	F_1F_5	F_4F_8

The Multi Frequency Algorithm proposed in [3] has been applied to the Pole Sensitivity analysis of Table 2 to diagnose faults. The voltage gain of the Circuit Under Test (CUT) is calculated at three different frequencies, cut-off frequency, one above the cut-off frequency and the other below the cut-off frequency. The gain of the CUT is normalized if necessary. The Gain vs Frequency is tabulated in Table 5. The three frequencies are $f_1=1$ KHz, $f_2=1.2$ KHz and $f_3=800$ Hz.

Table 5: Gain vs Frequency

S.No	Fault	Frequencies		
		f_1	f_2	f_3
1	F_1	678.58	762.73	587.1
2	F_5	715.73	807.38	587.14
3	F_2	704.08	798.89	621.27
4	F_6	660.63	748.26	568.03
5	F_3	695.3	777.7	591.52
6	F_7	695.3	784.38	591.52
7	F_4	671.17	823.97	608.59
8	F_8	671.16	755.01	608.59



As seen the frequency f_1 could not isolate the faults F_3 , F_7 , F_4 and F_8 and the frequency f_3 could not isolate faults F_1 , F_5 , F_3 , F_7 , F_4 and F_8 . **The frequency f_2 has been able to isolate all the eight faults.** Therefore the frequency $f_2= 1.2$ KHz is the test frequency and has thus been able to isolate all the faults.

5. RESULTS AND CONCLUSIONS:

In this paper Pole Sensitivity analysis in association with Multi Frequency approach has been proposed. The algorithm proposed has been able to successfully isolate maximum number of faults. The algorithm has been applied on a Band Pass Filter and has been able to achieve 100% fault diagnosis.

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Author's Biography

S.P. Venu Madhava Rao: He did his PhD from the prestigious JNTU, Hyderabad in the area of Analog VLSI Fault Diagnosis. His research areas include Nano Electronics, VLSI Analog Fault diagnosis, Machine learning etc. At present he is working as Professor and Head, Department of ECE in Sreenidhi Institute of Science and Technology, Hyderabad.

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