

TEST FREQUENCY SELECTION IN ANALOG FAULT DIAGNOSIS. PART II: RESULTS

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Key words: Analog circuit, Fault diagnosis, Sensitivity.

A new procedure for test frequency selection is proposed. The evaluation of the sensitivity functions versus frequency for the unknown parameters is employed. The sensitivity magnitude is used as a criterion for the test frequency selection. In this part the simulation results illustrating the proposed algorithm for test frequency selection are presented.

1. INTRODUCTION

Modern analog circuit development has as result many new analog electronic circuits with not only greater complexity but also with circuit elements being inaccessibly embedded within circuit chips. Consequently, there is a great interest in systematic fault diagnosis and isolation techniques for analog circuits where direct access to the individual circuit elements is no longer needed.

In the first part of this paper [1], various approaches to the analog fault diagnosis as well as its theoretical background are presented. Testability and groups of ambiguity [2-10], fundamental concepts in analog fault diagnosis, are emphasized. The main steps of the algorithm to solve a problem of analog fault diagnosis in SAT (simulation after test) approach are analyzed. The proposed test frequency selection algorithm and an exemplifying problem are described.

In the second part of this paper, there will be presented the simulation results, their analysis and the conclusions concerning the proposed method for frequency test selection.

2. RESULTS

The parameters of an equivalent circuit have to be identified. The equivalent circuit of an isolation transformer (Fig. 1) is described in paper [11] and the values of the three capacitors are given in [12]. The software packages SAPWIN [13] and

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MAPLE are employed for circuit analysis, transfer function computing, and advanced mathematic calculus. The Newton-Raphson method [14] implemented in MAPLE is employed to solve the system of nonlinear equations.

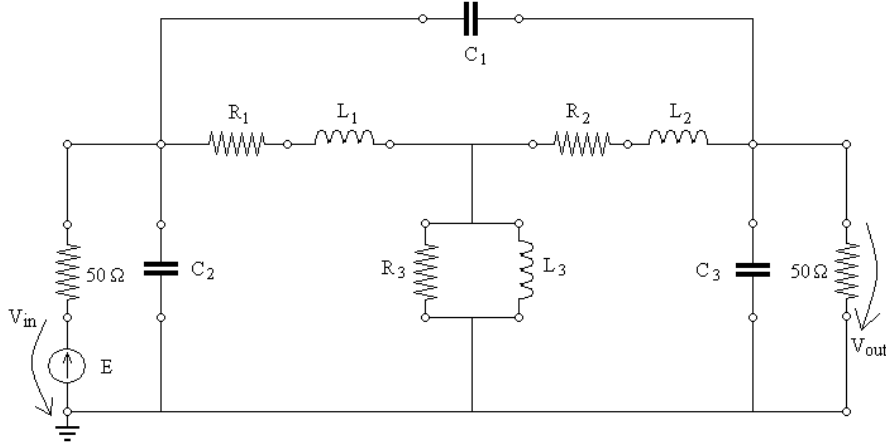


Fig. 1 – Equivalent circuit of an isolation transformer.

The rank of the testability matrix B is 5, so the number of testable components is 5. The two resistances R_1 and R_2 and the two inductivities L_1 and L_2 represent groups of ambiguity and can not be determined simultaneously. The testable component set is C_1 , C_2 and C_3 . The other parameters of the equivalent circuit are considered known: $R_1 = 0.28 \Omega$, $R_2 = 0.48 \Omega$, $R_3 = 1100 \Omega$, $L_1 = 3 \cdot 10^{-4} \text{ H}$, $L_2 = 3 \cdot 10^{-4} \text{ H}$ and $L_3 = 0.5 \text{ H}$.

In order to obtain the three necessary equations the module or/and the phase of the transfer function has to be evaluated for three frequencies. The transfer function coefficients are functions on the unknown parameters C_1 , C_2 and C_3 .

In the first case *the module of circuit functions* is used to generate equations for analog fault diagnosis. The sensitivities of the voltage gain

$A = \frac{V_{out}}{V_{in}} = |A| e^{j\varphi}$ ($|A|$ – voltage gain module, φ – voltage gain phase) are computed.

The sensitivity functions are: $S_{|A|}^{C_1} = \frac{\partial |A|}{\partial C_1}$, $S_{|A|}^{C_2} = \frac{\partial |A|}{\partial C_2}$ and $S_{|A|}^{C_3} = \frac{\partial |A|}{\partial C_3}$.

The sensitivity dependence on frequency considering the nominal values of C_1 , C_2 and C_3 are presented in Figs. 2, 3 and 4.

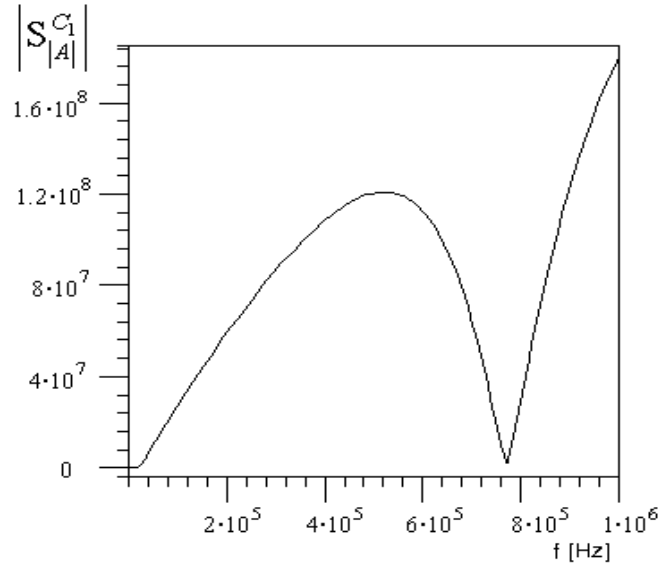


Fig. 2 – $\left|S_{|A|}^{C_1}\right|$ versus frequency.

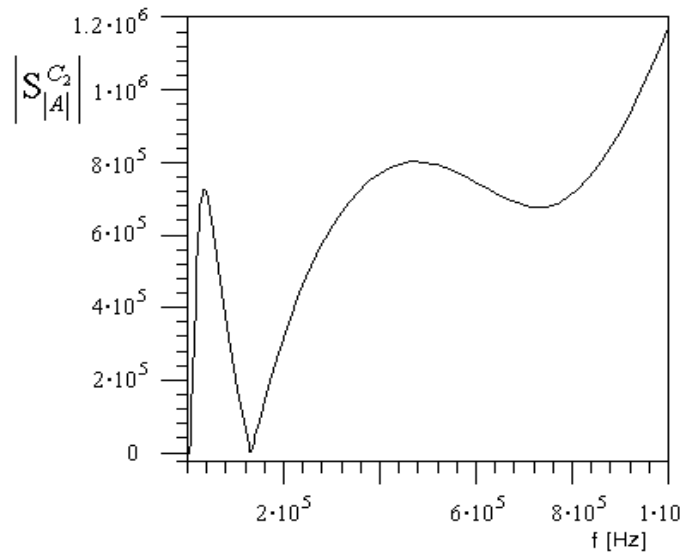


Fig. 3 – $\left|S_{|A|}^{C_2}\right|$ versus frequency.

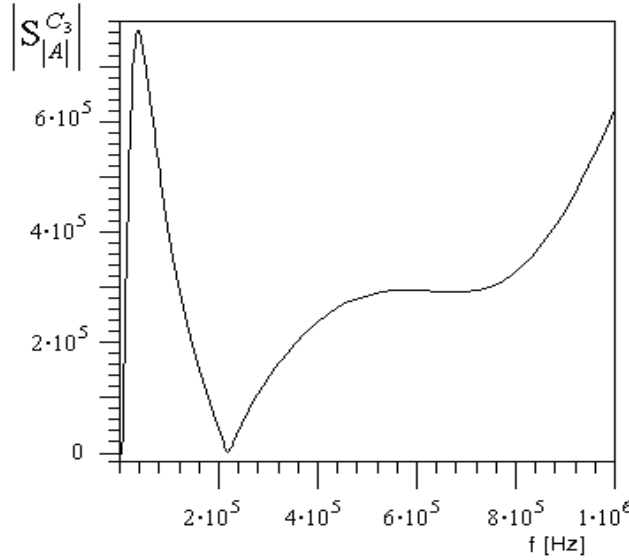


Fig. 4 – $|S_{|A|}^{C_3}|$ versus frequency.

The sensitivity analysis for identifying the zones where the optimal frequencies have to be chosen has been made on the basis of two criteria:

- the sensitivity values must be high;
- the difference between sensitivities (measured at the same frequency) must be also high.

The higher the sensitivity, the more influenced the function value is by an unknown parameter which is thus easier to compute.

The higher the difference between sensitivity characteristics, the more distinguishable is the influence of a certain parameter and thus, easier to identify

Therefore, as shown by our example, the optimal values of the frequencies are around $f = 30 - 40$ kHz where $|S_{|A|}^{C_2}|$, $|S_{|A|}^{C_3}|$ have maximal values. $|S_{|A|}^{C_1}|$ has a high value and the differences between $|S_{|A|}^{C_1}|$, $|S_{|A|}^{C_2}|$ and $|S_{|A|}^{C_3}|$ are also very high.

For example, for the following values $f_1 = 20$ kHz, $f_2 = 30$ kHz, $f_3 = 40$ kHz the algorithm is convergent and the solution is determined in 4 iterations (Fig. 7).

For other combinations 30, 40, 50 kHz, 40, 50, 60 kHz, and 50, 60, 70 kHz, it has been shown that the number of iterations increases as the sensitivity values decrease, although the difference between $|S_{|A|}^{C_2}|$ and $|S_{|A|}^{C_3}|$ increases (Fig. 6, 7).

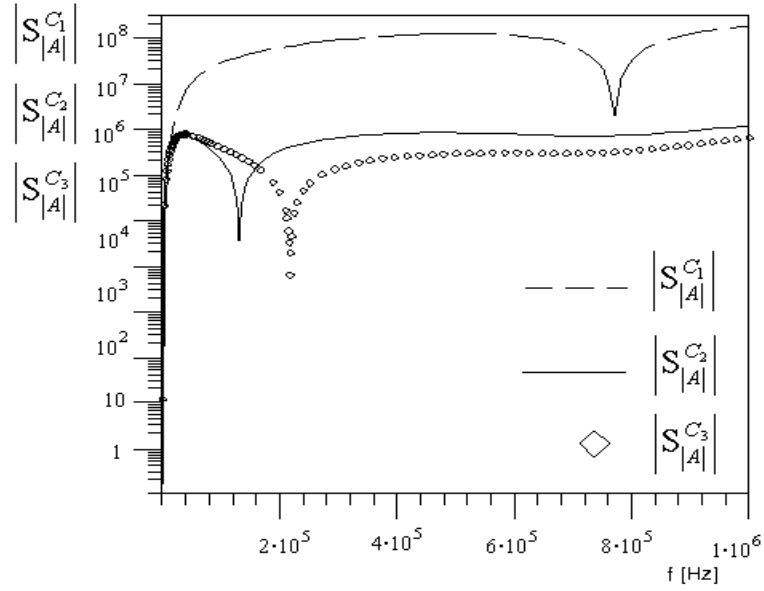


Fig. 5 – $|S_{|A|}^{C_1}|$, $|S_{|A|}^{C_2}|$ and $|S_{|A|}^{C_3}|$ versus frequency.

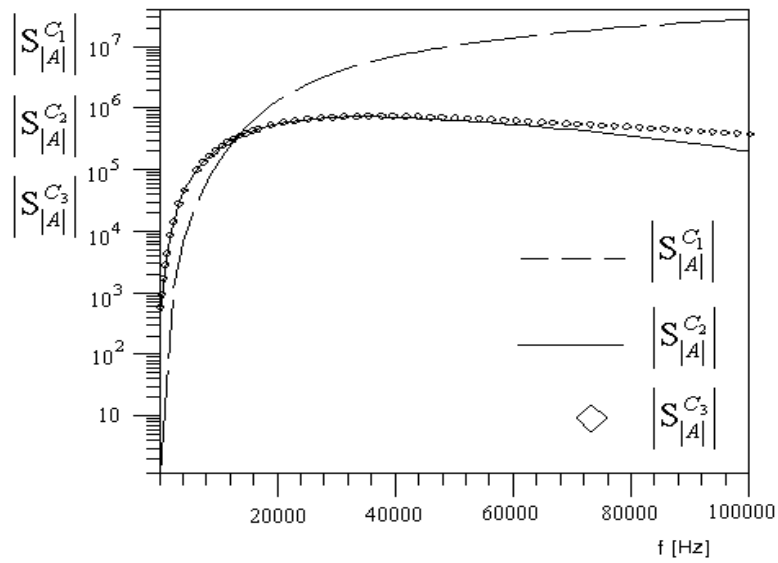


Fig. 6 – $|S_{|A|}^{C_1}|$, $|S_{|A|}^{C_2}|$ and $|S_{|A|}^{C_3}|$ versus frequency.

It results that the first criterion of the sensitivity magnitude is the main condition for choosing the optimal frequencies.

As shown in Fig.6 three sensitivities have approximately equal values, around $f = 13$ kHz, and consequently, their values are hard to be determined. It is harder to distinguish between their influences on the function value.

For example, for the following values $f_1 = 10$ kHz, $f_2 = 20$ kHz, $f_3 = 30$ kHz, where the difference between sensitivities is the smallest, the algorithm is not convergent.

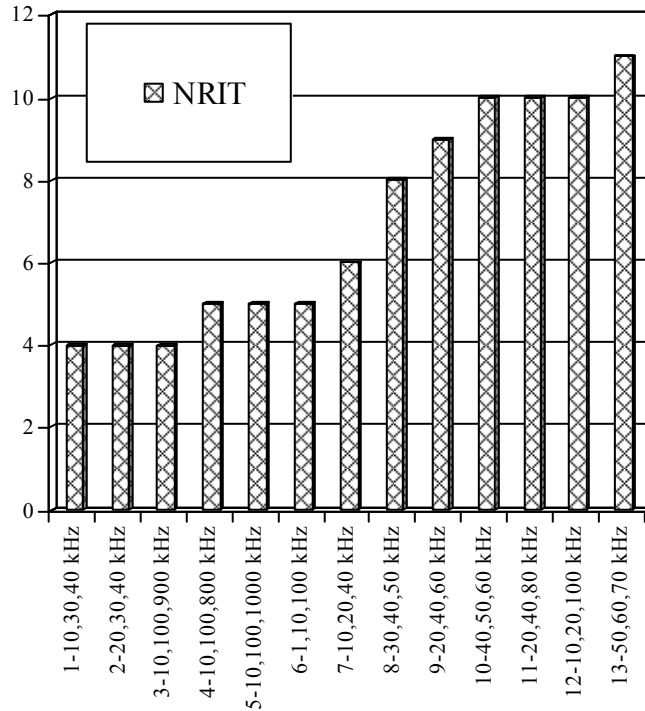


Fig. 7 – NRIT(number of iterations) versus set of frequencies(f_1, f_2, f_3).

For the set 10, 20, 40 kHz, the algorithm converges into six iterations but the solutions have a high level of error: $C_1 = 0.0454$ nF, $C_2 = 3.0147$ nF, $C_3 = 0.3855$ nF, $er_1 = 9.2\%$, $er_2 = 20.58\%$, $er_3 = 57.16\%$ (Fig. 7).

For the set 10, 30, 40 kHz, the algorithm converges into four iterations and the solutions have a high level of error: $C_1 = 0.0482$ nF, $C_2 = 2.7276$ nF, $C_3 = 0.6726$ nF, $er_1 = 3.48\%$, $er_2 = 9.19\%$, $er_3 = 25.26\%$ (Fig. 7).

The frequencies where sensitivities are null are $|S_{|A|}^{C_1}| = 0$ at 770 kHz, $|S_{|A|}^{C_2}| = 0$ at 130 kHz and $|S_{|A|}^{C_3}| = 0$ at 215 kHz (Figs. 2, 3 and 4). For the sets 50, 100, 200 kHz

and 100, 200, 300 kHz where the sensitivity $|S_{|A|}^{C_2}|$ is very small, the algorithm is not convergent.

Although the sensitivities and the difference between them are high, in the interval 400 kHz – 700 kHz and 800 kHz – 1000 kHz the algorithm is not convergent. The characteristics of the sensitivities have almost the same shape, are flat and approximately parallel in the interval 400 kHz – 600 kHz (Fig. 5). During the iteration of the Newton-Raphson method the Jacobian matrix becomes singular and the algorithm stops. For the sets: 300, 400, 500 kHz, 400, 500, 600 kHz and 700, 800, 900 kHz the algorithm is not convergent.

In the second case *the phase of network functions* is used to generate equations for analog fault diagnosis. The sensitivity functions versus frequency considering the values of the unknown parameters equal with their nominal values are presented in fig.8.

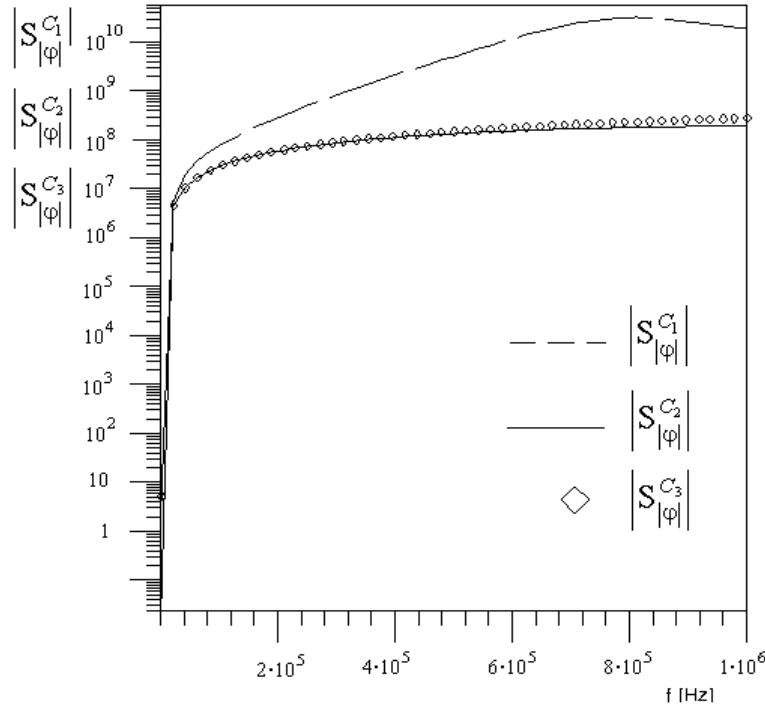


Fig. 8 – $|S_{|\varphi|}^{C_1}|$, $|S_{|\varphi|}^{C_2}|$ and $|S_{|\varphi|}^{C_3}|$ versus frequency.

The characteristics of the sensitivities have almost the same shape, are flat and approximately parallel in the interval 50 kHz – 900 kHz (Fig. 8). The Jacobian matrix becomes singular and the algorithm is not convergent.

As shown in Fig. 9 three sensitivities have approximately equal values, around $f = 19$ kHz, and consequently, their values are hard to be determined.

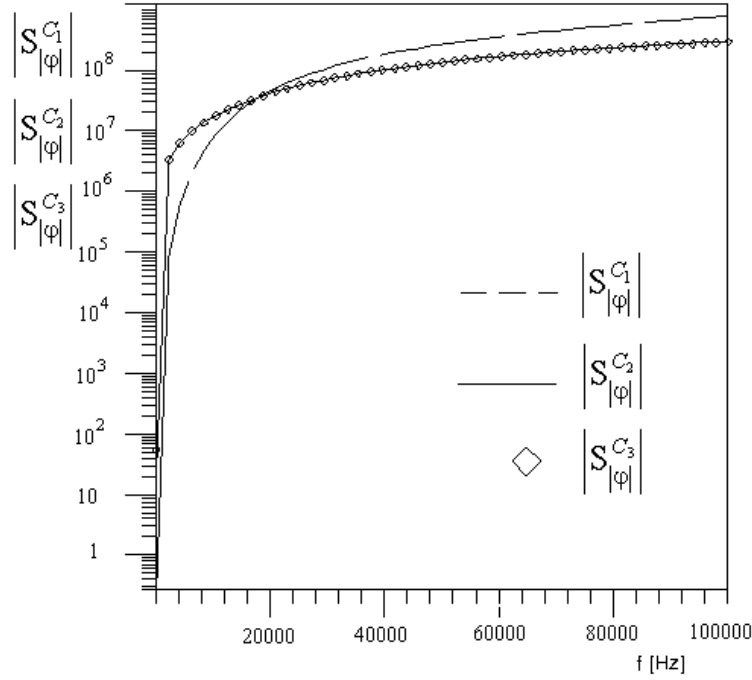


Fig. 9 – $|S_{|\varphi|}^{C_1}|$, $|S_{|\varphi|}^{C_2}|$ and $|S_{|\varphi|}^{C_3}|$ versus frequency

The conclusions are the same as in the first case.

Both the module and the phase of network functions can be equally used to generate equations for analog fault diagnosis.

3. CONCLUSIONS

The frequencies that permit the optimal solving of the analog fault diagnosis problem can be found in the frequencies ranges where all sensitivities have high values.

The big differences between sensitivities favor the solving of the problem because the influence of parameter values is easier to distinguish.

The frequency ranges where the sensitivities have very close values must be avoided. In this case solutions are computed with a high level of error.

The frequencies ranges where the sensitivities characteristics vs. frequency are flat and parallel or have the same shape must be avoided. In this case, the Jacobian matrix becomes singular and the Newton-Raphson algorithm is not convergent.

This properties of the sensitivity matrix lead to near minimum value of its condition number [10].

The test frequencies can be spaced linearly, or in any other way with the condition to be chosen in the permitted intervals.

Both the module and the phase of network functions can be equally used to generate equations for analog fault diagnosis.

Further work:

1. A program to implement the automatic selection of the frequency test set based on the ideas presented in the paper.
2. The generation of fault diagnosis equations based on module as well as phase functions.
3. The generation of fault diagnosis equations based on pole/zero symbolic expressions.

Received on 31 January 2007

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