Fifth IFSA World Congress (1993), 1402-1405

Fault Evaluation Based on Fuzzy Logic for Analog Electronic Circuits

Masaki Hashizume, Yoshihiro Iwata, Takeomi Tamesada

Faculty of Engineering, The University of Tokushima
Tokushima-shi Tokushima, 770 JAPAN

Abstract

In this paper, a fault evaluation method is proposed, which is to determine whether analog electronic circuits are faulty or not. In our method, evaluation characteristics of an expert test engineer are defined by means of directed graphs. By performing a multi-stage fuzzy inference based on the graphs, novice test engineers can derive a fault evaluation result satisfied by the expert. The effectiveness of our method is checked by some experiments for an amplifier circuit.

1. Introduction

It is very difficult to determine whether analog electronic circuits are faulty or not, because even if a circuit element is not damaged fully and has a value, which is different from the one of the unfaulty circuit, the circuit may work well in many cases. The difficulty makes it more difficult to diagnosis analog electronic circuits[1,2]. Thus until now, analog circuits have been diagnosed by only a small number of expert test engineers. Since it has been demanded to implement high reliable analog circuits, it has been strongly requested to develop a fault evaluation method.

The difficulty in the fault evaluation of analog circuits is caused by the existence of some fuzziness in the criterion of judgment for determining whether the circuits are faulty or not. A fault evaluation problem can be formalized as a subjective evaluation problem. Therefore, it may be solved by using fuzzy measures[3,4]. However, since there are many factors that effect on the final evaluation result, they are not applicable to many fault evaluation problems of analog electronic circuits. Therefore, in this paper, we propose a new fault evaluation method.

2. Fault Evaluation Method

2.1 Philosophy

Our goal is to develop a fault evaluation method, with which the productivity of analog circuit tests can be made to improve. Until now, analog circuits have been diagnosed by expert test engineers. Therefore, we attempted to develop a method, with which novice test engineers can derive an evaluation result satisfied by an expert test engineer. If the fault evaluation characteristics of an expert test engineer are stored in a test system by using our method, a test engineer can obtain a fault evaluation result only by answering questions provided from this system.

Generally, a result obtained by evaluating what degree the circuit is faulty is different from the one obtained by evaluating what degree it is unfaulty. By providing both results, it can be expressed more precisely what extent the circuit is faulty. Therefore, μ_{Fi} and μ_{Ni}, which are the evaluation results of the i-th evaluation factor obtained by evaluating what degree the factor is unpreferable and preferable, respectively, are derived for all factors by our method. After that, both μ_{FT} and μ_{NT} as final evaluation results are derived with the μ_{Fi}'s and the μ_{Ni}'s, where μ_{FT} and μ_{NT} are the results obtained by evaluating what degree the circuit is faulty and is unfaulty, respectively.

2.2 Evaluation Graph

There are many evaluation factors which have an effect on μ_{FT} and/or μ_{NT}. They are classified into 2 kinds of factors; ones are factors whose evaluation characteristics of an expert test engineer can be defined with membership functions and the others are factors whose evaluation results can be obtained from other factors. The former factors correspond to the ones concerned with the circuit specifications of a circuit under test(CUT). For example, in a fault evaluation problem of the circuit in Fig.1, an evaluation characteristic curve for the voltage gain can be defined by a membership function. On the other hand, an evaluation result on the frequency response can not be determined with any membership functions. It can be obtained from evaluation results on the lower cut-off frequency(f_L) and the higher cut-off frequency(f_H). The relations among factors can be defined by a directed graph as shown in Fig.2. For many other circuits, these relations can be defined with such graphs, which are referred to as "**evaluation graphs**" in this paper.

If the functions of a CUT are not performed fully, the circuit can be determined as a faulty one. Even if the functions are performed fully, the circuits, whose good performances are not obtained, can not be determined as an unfaulty circuit. Thus, both μ_{FT} and μ_{NT} depend on whether the required functions of the circuit are performed, and/or whether the expected performances are obtained. That is, final evaluation results are determined by the evaluation results on the functions and the performances. Therefore, at the top level of our evaluation graph, the relation among them is defined as shown in Fig.2.

Some functions and performances of analog circuits can be defined in detail by other factors. For example, the factor on the frequency response of the circuit in Fig.1 can be defined with f_L and f_H. Therefore, arrows from f_L and f_H to the frequency response are drawn in the evaluation graph, which are used for expressing the inference relation.

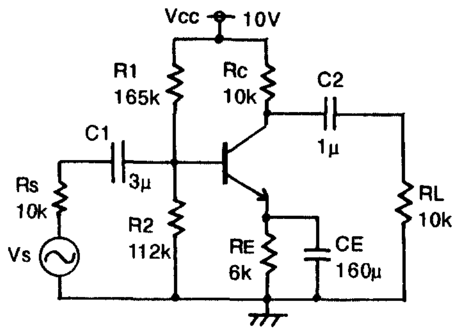


Fig.1 Amplifier circuit(CE Amp.).

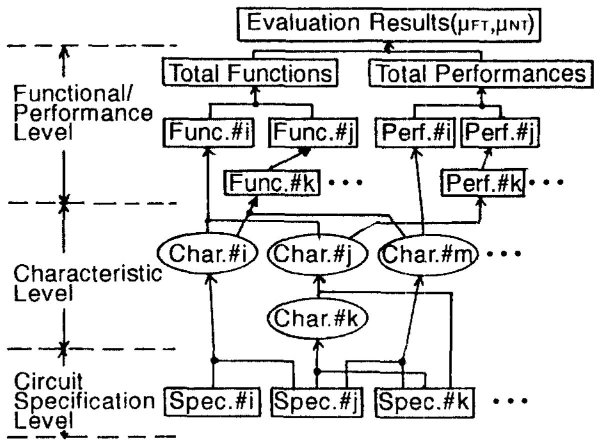


Fig.2 Evaluation graph

Table 1 Meanings of abbreviations in Fig.2 in the derivation process of μ_{FT}

Abbreviation	Meaning
Func.#i	The i-th function is abnormal.
Perf. #i	The i-th performance is beyond the permissible range.
Char.#i	The i-th characteristic is abnormal.
Spec.#i	The i-th specification does not satisfy the design request.

Table 2 Meanings of abbreviations in Fig.2 in the derivation process of μ_{FN}

Abbreviation	Meaning
Func.#i	The i-th function is performed.
Perf. #i	Required i-th performance is obtained.
Char.#i	Required i-th characteristic is obtained.
Spec.#i	The i-th specification satisfies the design request.

The process to make more detail the functions and the performances will be continued until all the circuit specifications are connected to any factors. As the result, our evaluation graph consists of 3 kinds of hierarchy levels as shown in Fig.2. In evaluation graphs, only keywords are described, whose meanings are shown in Table 1 and 2.

Generally, an evaluation graph for μ_{FT} is different from μ_{NT}. Therefore, two graphs are defined in our method, that is, one for μ_{FT} and the other for μ_{NT}.

2.3 Inference Based on Evaluation Graphs

When an evaluation result of a factor is obtained from other factors by using such an evaluation graph, it should be considered the difference of the importance among the factors. For example, the circuit in Fig.1 is an amplifier circuit. Thus, the evaluation result of the amplitude characteristic has more effects on the final evaluation results than the power dissipation characteristic. Therefore, for each factor, a weight (w_i, $0 \le w_i \le 1$) is defined in our method.

When μ_{Fi} is derived from other evaluation results, an additional effect should be considered. The effect depends on the degree of distinction among the factors and on the importance of the evaluation. Our method can not always derive the exactly same evaluation result as the one of expert engineers, since our method is an approximate implementation of their evaluation mechanisms. Therefore, our method derives a greater evaluation result than the expert, so that faulty circuits can not be determined as unfaulty.

When a factor C is determined from the evaluation results of factors A and B, the evaluation result μ_{FC} is derived by using Eq.(1).

$$\mu_{FC}=\begin{cases} w_A \cdot \mu_{FA}+(1-k_{AB})\cdot(1-w_A \cdot \mu_{FA})\cdot w_B \cdot \mu_{FB}, & \text{if } \mu_{FA} \ge \mu_{FB} \\ w_B \cdot \mu_{FB}+(1-k_{AB})\cdot(1-w_B \cdot \mu_{FB})\cdot w_A \cdot \mu_{FA}, & \text{if } \mu_{FA} < \mu_{FB} \end{cases} \quad (1)$$

where

μ_{FA} and μ_{FB} are evaluation results of A and B, respectively, w_A and w_B are the weights of A and B, respectively, and k_{AB} ($0 \le k_{AB} \le 1$) is a coefficient for expressing the degree of the additional effect.

In Eq.(1), k_{AB} is determined by considering the similarity between A and B, that is, what extent they express the same characteristics of the circuit. If the factor A is independent of the factor B, k_{AB} is set to 0.

In many cases, μ_{FT} can be determined by an evaluation result of only a factor. For example, when μ_{Fi} of the voltage gain in Fig.1 is extremely large, the circuit can be determined as a faulty one. Therefore, in our method, α_{Fi}, which is the upper bound of μ_{Fi}, can be defined for each factor, and if $\mu_{Fi} \ge \alpha_{Fi}$ for a factor, μ_{FT} is set to be 1. If μ_{Fi} is less than the upper bound for all factors, μ_{FT} is derived by using the evaluation graph.

For μ_{NT} and μ_{Ni}, any additional effects are not used in our method. They are calculated by the same method as in [5,6]. For each factor, α_{Nj}, which is the lower bound of μ_{Nj}, is specified. If $\mu_{Nj} \ge \alpha_{Nj}$ for all factors, μ_{Ni} is calculated by using a convex fuzzy decision with weights. Otherwise, the minimum value is used as μ_{Ni}, as shown in Eq.(2).

$$\mu_{Ni}=\begin{cases} \sum_{j=1}^{Np} (w_j \cdot \mu_{Nj}) \Big/ \sum_{j=1}^{Np} w_j, & \mu_{Nj} \ge \alpha_{Nj}, \text{for } \forall j \\ \min(\mu_{Nj}), & \text{Otherwise} \end{cases} \quad (2)$$

where Np is the number of factors, which are used for determining μ_{Ni}.

3. Fault Evaluation of Amplifier Circuit

Fig.3 shows evaluation graphs used in our fault evaluation experiments on the circuit in Fig.1. The performances of the circuit are obtained by using PSpice[7]. In our experiments, R1 in Fig.1 is changed from 0 to 400kΩ. The results are shown in Fig.4. Also, in order to check the effectiveness of our method, we derived fault evaluation results by using λ-fuzzy measure, which are shown in Fig.5

From Fig.4, it is found out that the evaluation results of our method can satisfy the criterion of judgment of expert test engineers. However, as shown in Fig.5, the evaluation results obtained by using λ-fuzzy measure can not satisfy it. For example, μ_{NT} is not 0 for the larger values of R1, and there exist unacceptable changes in the curves of both μ_{FT} and μ_{NT} for the smaller values of R1. Furthermore, in our method, it is easier to define the evaluation mechanism of an expert than the method, since the number of factors, among whose evaluation characteristics should be defined, can be decreased by using evaluation graphs.

4. Conclusion

A fault evaluation method is presented in this paper, in which evaluation mechanisms of an expert test engineer are defined by means of directed graphs. By using the graphs, a fault evaluation result is derived, which is satisfied by the expert. It is found that the method is more suitable for the evaluations than the method based on λ-fuzzy measure, by performing some fault evaluations of an amplifier circuit.

References

[1]J.W.Bandler and A.E.Salama : "Fault Diagnosis of Analog Circuits", Proc. of IEEE, Vol.73, pp.1279-1325(1985).

[2]M.Slamani and B.Kaminska : "Analog Circuit Fault diagnosis Based on Sensitivity Computation and Functional Testing", IEEE Design&Test of Computers, pp.30-39(March,1992).

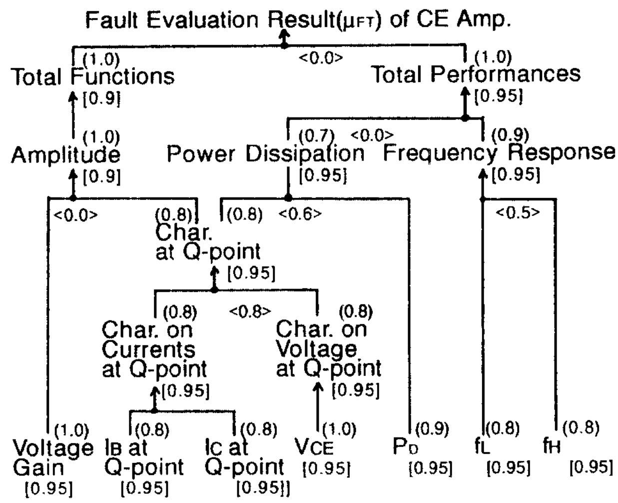
[3]H.J.Zimmermann : "Fuzzy Set Theory and Its Applications - Second Edition", pp.45-51, Kluwer Academic Publishers(1991).

[4]K.Ishii and M.Sugeno: "A Model of Human Evaluation Process Using fuzzy Measure", International Journal of Man-Machine Studies, No.22, pp.19-38(1985).

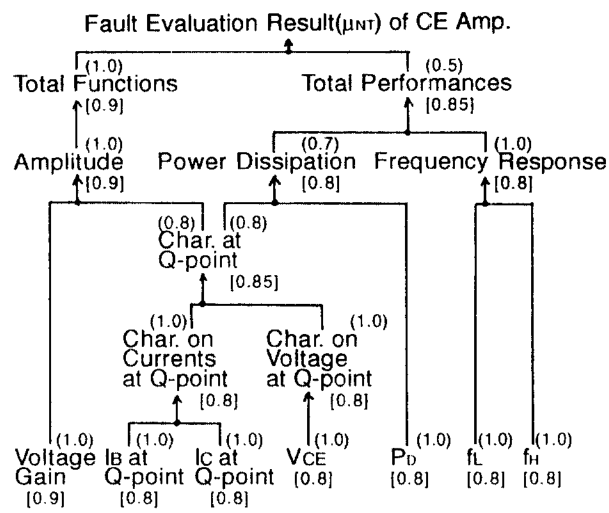
[5]M.Hashizume, T.Tamesada and K.Nii : "A Parameter Adjustment Method for Analog Circuits Based on Convex Fuzzy Decision Using Constraints of Satisfactory Level", IEEE ICCD-90,pp.24-28(1990).

[6]M.Hashizume T.Tamesada and H.Yoshihara : "A Practical Solution Using Expertise Knowledge of Fuzzy Multiobjective Programming Problems with Lower Satisfactory Level Constraints", IFES-91, pp.1059-1067(1991).

[7]P.W.Tuinenga : "SPICE A Guide to Circuit Simulation and Analysis Using PSpice", Prentice Hall(1988).



(a) Evaluation graph for μ_{FT}



(b) Evaluation graph for μ_{NT}

Fig.3 Fault evaluation graph for CE amplifier circuit
(The numbers in (),[] and <> are w_i, α_i and k_i, respectively.
PD: DC Power Dissipation)

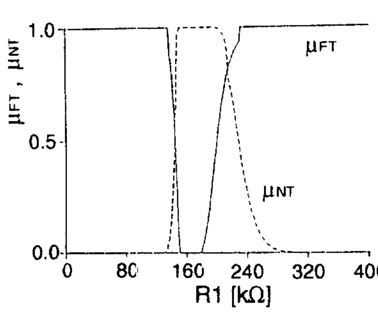
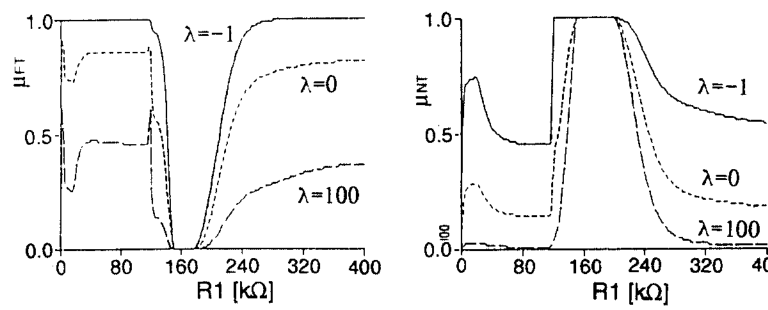


Fig.4 Obtained fault evaluation results for the circuit in Fig.1.



(a) μ_{FT} (b) μ_{NT}

Fig.5 Evaluation results obtained by using fuzzy measure.