FAULT DETECTION AND DIAGNOSIS IN ANALOG CIRCUITS USING FUZZY TECHNIQUES FOR SIGNAL ANALYSIS

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ABSTRACT

One simple and well-known way used in manual inspection of analog circuits by the debuggers consists in applying at the circuit input some typical signals (as sine waves, square wave, saw-tooth) and examining the circuit response to these input stimuli, both at its primary output and at different test points in the circuit. The debugger knows how the correct circuit should respond to each of these stimuli, and if the expected signal doesn't appear at the output, it means that there is a fault in the circuit; to be able to identify it, he must know what type of fault produces that type of signal distortion. This is the typical situation in analog circuit diagnosis. We propose and build here a fuzzy logic-based expert system to emulate the human circuit debugger. We employ fuzzy techniques to perform the analysis of the analog signals introduced to and generated by the circuit and to generate the decision about the absence/presence of the faults and about their nature. The results obtained are according to the expert's expectations, thus proving the good functionality of the system. The system for analog circuit diagnosis proposed can be useful for analog system diagnosis.

KEYWORDS: fuzzy logic, analog circuit diagnosis, expert systems, fuzzy signal modeling, fault detection

1. INTRODUCTION

One simple and well-known way used in manual inspection of analog circuits by the debuggers consists in applying at the circuit input some typical signals (as sine waves, square wave, saw-tooth) and examining the circuit response to these input stimuli, both at its primary output and at different test points in the circuit. The debugger knows how the correct circuit should respond to each of these stimuli, and if the expected signal doesn't appear at the output, it means that there is a fault in the circuit; to be able to identify it, he must know what type of fault produces that type of signal distortion. This is the typical situation in analog circuit diagnosis.

Since this kind of human behavior proved to be efficient for decades in analog circuits diagnosis, even for complex systems, and since unlike in the case of digital circuits diagnosis, there are no well established test strategies, we consider that a computer modeling of this human test strategy can lead to valuable results for fault detection in analog circuits. Such a human behavior modeling is the purpose of our paper; since fuzzy logic is the best known tool to model the human knowledge in computer systems, we use fuzzy techniques to perform the analysis of the analog signals introduced to and generated by the circuit, and also to generate the decision about the absence/presence of the faults and about their nature [1].

2. THE PROPOSED STRUCTURE OF THE ANALOG CIRCUIT DIAGNOSIS FUZZY SYSTEM

The structure of the system proposed for the analog circuit diagnosis, based on the signal analysis in different points of the circuit, is shown in Figure 1.

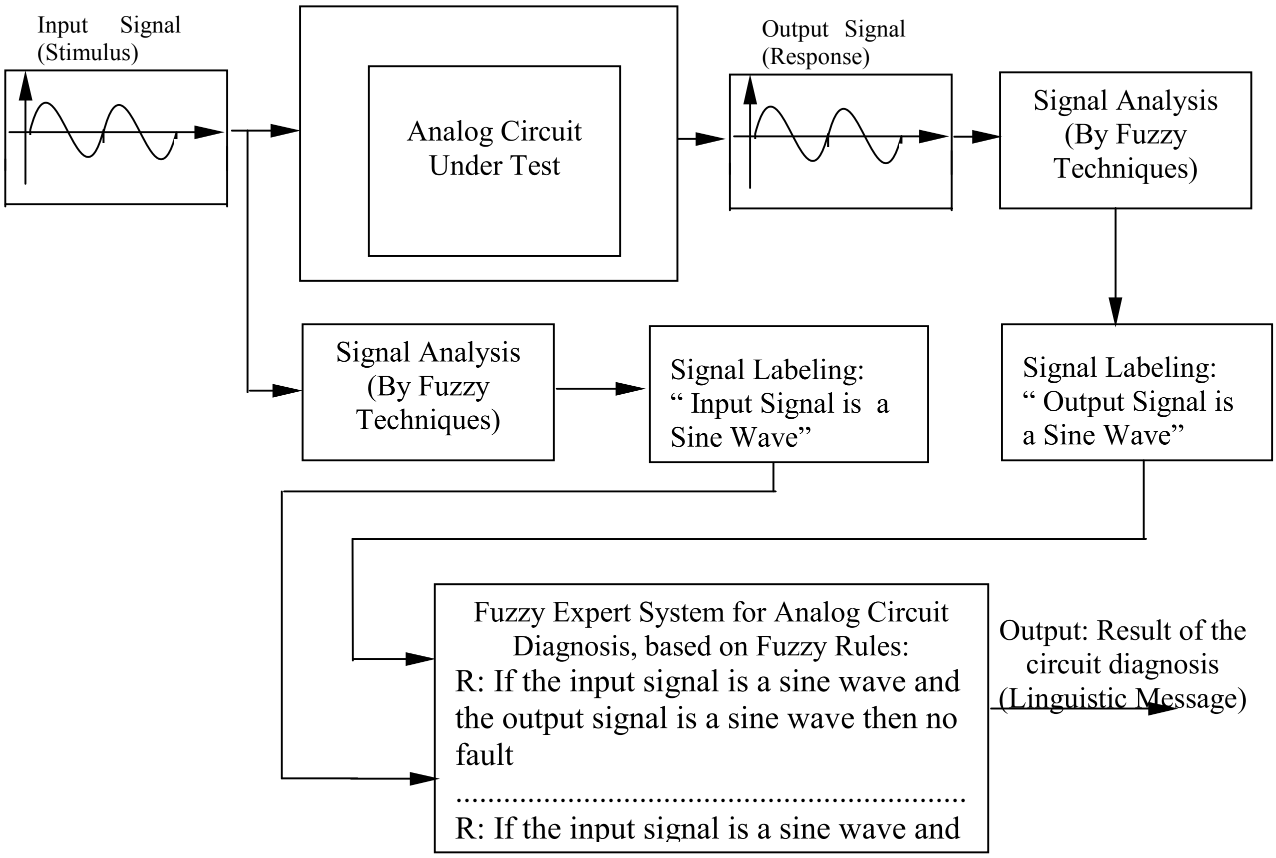


Figure 1. The schematic diagram of the fuzzy system proposed for analog circuit diagnosis

The diagnosis is performed by the system in the following sequence of operations: **first**, an input stimulus (an analog signal) is applied at the circuit input. This signal belongs to a class of analog signals to which the circuit gives relevant responses in term of the output signal type; the class of input signals forms the test sequence for the analog circuit considered, and is provided by the human debugger based on its experience, or by the manufacturer of the circuit.

Then, a parallel processing is applied to this input signal and to the circuit response (output signal), which mainly consists in a computer analysis of each signal (input and output). The analysis is based on fuzzy techniques, and aims at recognizing the signal shape: sine wave, square wave, etc. The analysis performed here will be described in greater detail later, since it can be viewed as the ***core*** of our computer-based diagnosis system.

As a result of the signal analysis, a label is attached both to the input and output signal, showing its degree of belonging to one or more classes of signals. For now, only a few typical types of signals are considered: sine, square, limited sine, trapezoidal and triangular wave, but the extension to other types is easy to be done. The type of signal can be viewed as a linguistic variable, and each label can be viewed as a linguistic value of the linguistic variable. The linguistic value denoted by the label and the degree of "validity" of the label represents the input to be processed by the fuzzy expert system, according to its fuzzy rules.

The **fuzzy expert system** is the "brain" of our computer-based diagnosis system shown in Figure 1. It contains a number of ***"If…Then…"*** rules, linguistically expressed, derived from the human experience about the fault occurrence and detection for the circuit considered. Based on the input values generated by the fuzzy signal analysis blocks and on these fuzzy rules, a fuzzy inference process takes place, which generates as the result a linguistic message showing: the presence/absence of faults in the circuit; information about the position and possible cause of the fault, also specifying the degree in which this decision regarding the fault detection is true.

In general, to express the rules of the fuzzy expert system in linguistic if-then format is a simple task to perform, as it is for any fuzzy system based on human experience. The harder thing to do is to give a mathematical definition of the linguistic values that appear in the antecedent and consequent of each rule; for example, for an analog filter, in the band-pass region, it is easy to express a rule of the type: "If the **input signal** is a ***sine wave*** and the **output signal** is a ***sine wave*** then ***no fault***", but is harder to define the term ***sine wave*** according to the human meaning for this term, because when talking about a sine wave, the human means "*a signal that **looks like** a sine*", which means, a sine is just an *approximate* sine.

The task of defining these linguistic values is assigned to the ***fuzzy signal analysis*** block; that's why we consider it the most important for our computer-based diagnosis system. The fuzzy signal analysis is conceived as a fuzzy pattern recognition system [2]. At the input of the fuzzy signal analysis block, the input signal is represented as a black&white image of the signal time-plot, where the black pixels represent the signal and the white pixels-the background. This image is input to a preprocessing block that retains only one "approximate" period of the signal for further processing.

On the other hand, the fuzzy signal analysis block has a knowledge base containing ***fuzzy image models*** of all the signals considered as input stimuli for the circuit under test. These fuzzy models can be viewed as fuzzy sets, labeled by the linguistic values (as for example, *sine wave*), and are derived based on the human perception. For example, in the case of a sine wave, a period of a pure sine signal will belong in the degree of 1 to the fuzzy set ***Sine Wave***, while a signal that the user defines categorically as not sine at all (for example, a period of a square wave) will belong in the degree 0 to the fuzzy set ***Sine Wave***.

The image of a period of the input signal obtained from preprocessing is entered in a ***fuzzy classifier*** [2], that computes the membership degrees of the stimulus to all the fuzzy models in the knowledge base, and passes these degrees as results to the fuzzy expert system.

The fuzzy signal analysis block for the output signal works just the same, but the knowledge base content is according to the human knowledge about the circuit response.

The block diagram of the fuzzy signal analysis block is shown in Figure 2.

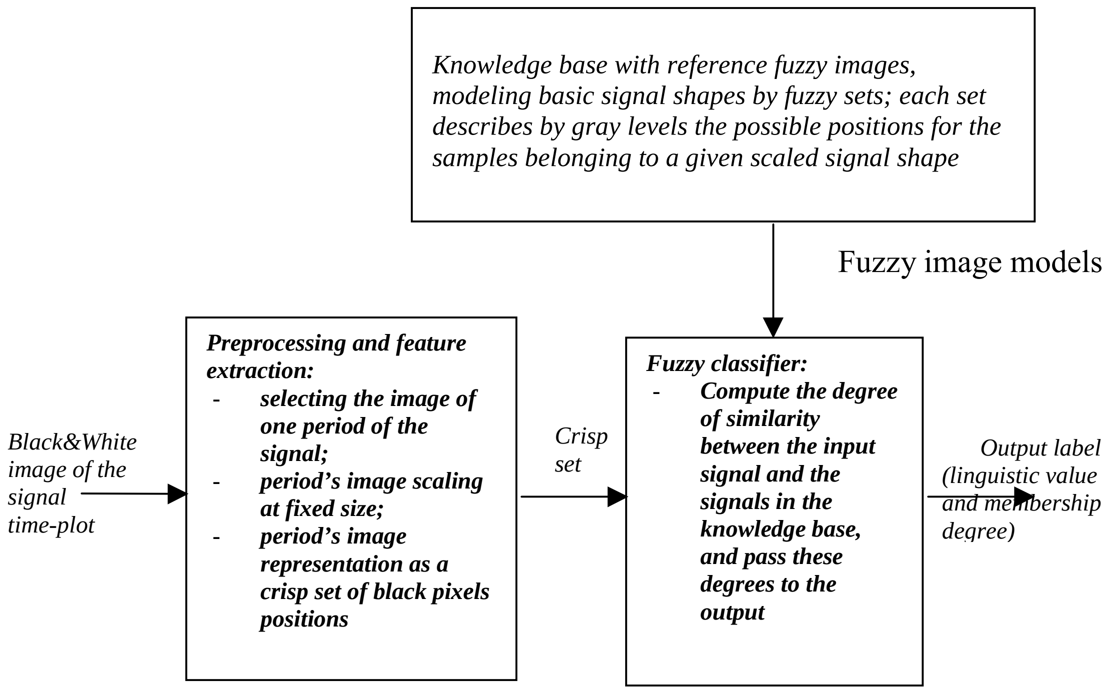


Figure 2. The diagram of the fuzzy signal analysis block

3. EXPERIMENTAL RESULTS

To evaluate the functionality of the proposed diagnosis system, we designed and implemented software in C++ the fuzzy system proposed for analog circuit diagnosis for the diagnosis of a simple OpAmp inverter amplifier. The system has a Windows interface to allow the interaction with the user, who can select the desired output: the correct expected response of the circuit for each possible stimulus considered, the response of the circuit under test for each possible stimulus or both of them on the same image. The diagnosis box specifies if the circuit under test is good or faulty, and the degree of maximum confidence in the functionality of the circuit is also provided. An operation example is illustrated in Figure 3.

The fuzzy signal analysis block was implemented also in C++, and is available also as a standalone application, with its own interface, as in Figure 4.

Since as we mentioned we consider in Figure 5.

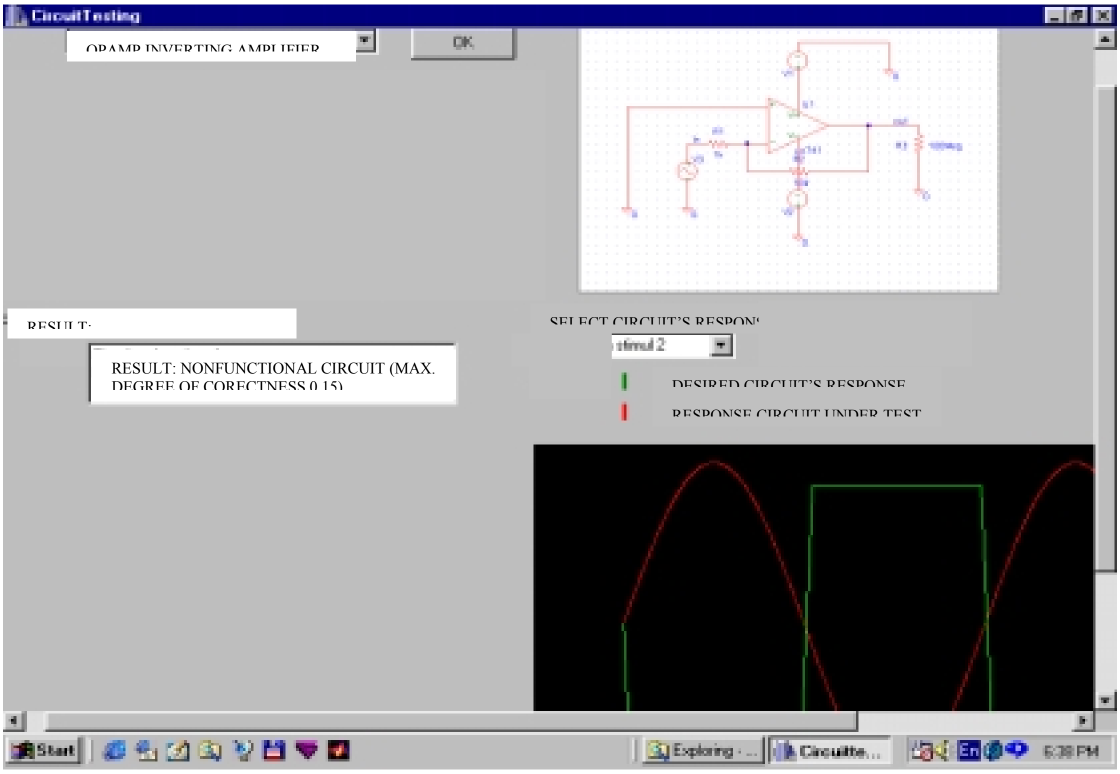


Figure 3. The interface and an operation example of the proposed diagnosis system

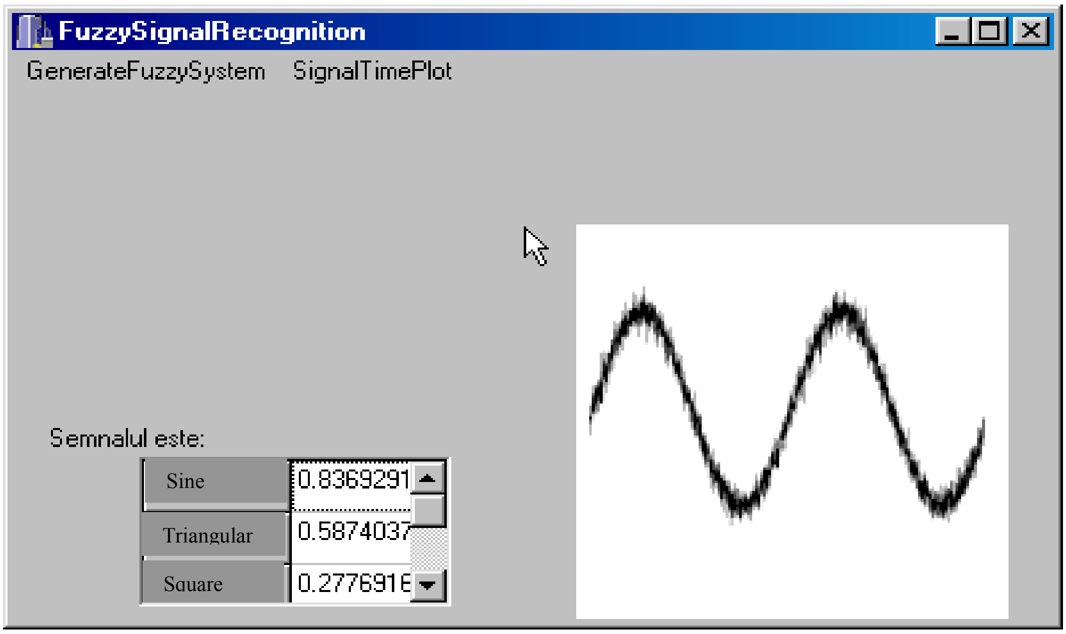
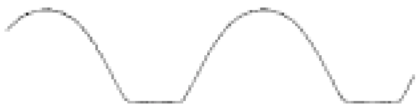


Figure 4. The fuzzy signal analysis block as a standalone application

Recognition results:
Sine Wave: 0.9
Square Wave: 0.28
Triangular Wave: 0.6

Recognition results:
Sine Wave: 0.32
Square Wave: 0.75
Triangular Wave: 0.19



Recognition results:
Sine Wave: 0.75
Square Wave: 0.36
Triangular Wave: 0.37

Figure 5. The fuzzy signal analysis block performances for 2 examples of stimulus and one (distorted) response.

The results obtained are according to the expert's expectations, thus proving the good functionality of the system.

4. CONCLUSIONS

We consider that the system for analog circuit diagnosis proposed here, based on the input and output signal analysis, can be very useful for making use of human knowledge in analog system diagnosis, which is still a very important resource for fault detection especially in complex systems. However, in this paper we discussed only simple situations, in order to highlight the idea; its generalization is just a matter of patience and hard-work.

The system structure is very suitable for software implementation and interfacing with hardware systems under test and also for hardware&software implementation on DSP systems, thus allowing a good compromise between the processing speed and the flexibility of the system (which must be open for including new fuzzy rules and new types of input/output signals).

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