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DESIGN OF SIGNATURE ANALYZER STRUCTURES WITH REQUIRED PROPERTIES

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ABSTRACT

A problem of signature analyzer synthesis with required properties is solved for digital schemes compact testing. The main attention is devoted to the issues of eliminating losses of diagnostic information and to simplicity of structural organization. Solutions are based on detecting all error vectors or matrices resulting from failures of diagnostics objects related to the postulated class. Any other error vectors or matrices can be non-detectable and are excluded from consideration. A software implementation of the mathematical model is proposed. Error vectors or matrix detection process visualization aids are given.

Keywords: linear sequential machine, signature analyzer, errors vector, errors matrix.

INTRODUCTION

Self-testing of diagnostics objects (DO) is a maximally self-contained method of embedded diagnostics testing, because the generation of test inputs and analysis of the results of test information are not supported by the system facilities [1]. Actually, any self-testing method is based on test impacts generation and compact representation of test impact passage results. Therefore, the problem of sound selection of embedded equipment parameters is essential for any DO manufacturing process [2, 3].

Currently the need for cost-effective testing systems is increasing due to the enhanced level of integration of computing equipment component base. Therefore, the trend toward decreasing the complexity of diagnostic facilities hardware exists. Built-in test aids are of great importance, for example, in large and extra-large integrated circuits development [3, 4].

The methodology of digital systems diagnosis based on transformation of binary sequences coming to the DO into compact specifications - signatures, comparison of obtained signatures with reference signatures, and corresponding processing of comparison results -- are the essence of signature analysis [5-7]. As a rule, mathematical tools from antinoise coding theory are used as a theoretical apparatus for signature analyzer development. However, theoretical substantiation of the development of hardware signature analyzers (SA) with required properties is most advantageous when based on the mathematical tools of linear sequential machines (LSM) [8].

A classical signature analyzer is in principle unable to detect all possible combinations of errors. Some part of them will never appear at the DO output, and therefore there is no need to detect them. The following task is posed in this paper: to build a simple signature analyzer that would detect all DO errors caused by the faults from the postulated class.

A LINEAR SEQUENTIAL MACHINE AS A SIGNATURE ANALYZER

Processes in LSM with l-inputs, m-outputs, and n-memory elements (Figure-1) are described by linear system of state equations and linear system of output equations, which appear as follows in matrix form:

$$S^{t+1} = AS^t + BU^t,$$

$$Y^t = CS^t + DU^t,$$

where
$A = \|a_{ij}\|_{n\times n}, B = \|b_{ij}\|_{n\times l}, C = \|c_{ij}\|_{m\times n}, D = \|d_{ij}\|_{m\times l}$
the characteristic matrices.

Input U^t, output, Y^t and S^t LSM state at a time moment t are specified in the form of corresponding column vectors $U^t = \|u_i^t\|_l, Y^t = \|y_i^t\|_m, S^t = \|s_i^t\|_n$.

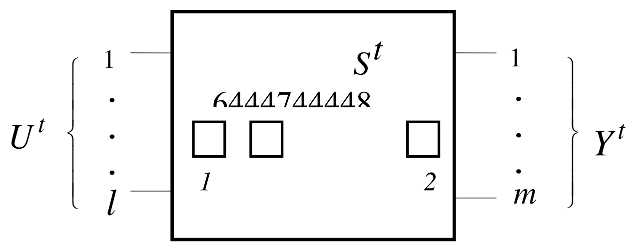

Figure-1. The structure of a linear sequential machine.

The structure of LSM is described by the matrix of the connection A of memory elements, in which every element a_{ij} is defined as follows:

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$$a_{ij} = \begin{cases} 0, & \text{if the output of the } j\text{-th memory element is connected to the input of the } i\text{-th memory element;} \\ 1, & \text{otherwise.} \end{cases}$$

Other matrices can be interpreted similarly, matrices which set links between inputs and memory elements (B), between memory elements and outputs (C), and between inputs and outputs (D).

It is expedient to implement the analysis of DO responses l with the outputs for test input under conditions of limited resources for additionally introducing hardware, by connecting LSM l with inputs (Figure-2), and this will serve as the signature analyzer.

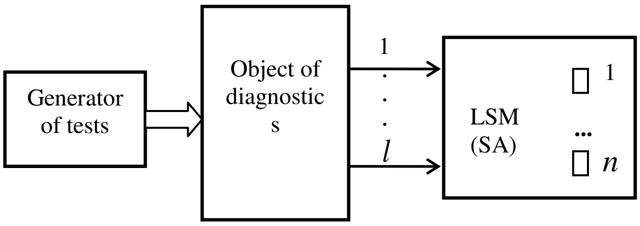


Figure-2. Diagnostics object with signature analyzer.

When DO testing is complete, SA memory element states will be equal to modulo two sum of the reference signature R_{st} and R_{er} error signature $R_{st} \oplus R_{er}$. At that, a failure will be revealed if $R_{er} \neq 0$.

A method of deriving signatures and proof of the effectiveness of their use are essential here, i.e. the possibility of detecting errors with an acceptable probability after compression of binary sequences. It is known that the probability of not detecting an error P_{ud} in a sequence of interchangeable logical states at DO output ($l=1$) is equal to [1, 9]: $P_{ud} = \dfrac{2^{N-n}-1}{2^N-1}$, where N - is the length of the sequence, n – is the number of SA digits ($N >> n$). In other words, compressing a long sequence into a short signature is associated with diagnostics information loss.

It is proposed to exclude recognition ambiguity inherent to compact testing, as follows. It is necessary to build LSM that detects the entire set of error vectors ($l=1$) or matrices ($l \geq 2$) of DO response to the control test which are caused by the specification of failures from the postulated class. Of course, there is no need to reveal vectors or matrices of errors which cannot appear at DO outputs in principle.

A SIGNATURE ANALYZER WITH REQUIRED PROPERTIES

Let there be an l -output digital network, and a sequence of tests consisting of N binary sets comprising a full test for it; i.e., ensuring the appearance of any fault from the postulated class at the network outputs $S=\{s_\nu\},\ \nu=\overline{1,M}$.

Let us name the matrix of the ν -th error caused by a fault $s_\nu \in S$ as $E^\nu = \left[e_{ij}^\nu\right]\ i=\overline{1,l};\ j=\overline{0,N-1}$, in which each element e_{ij}^ν is defined as follows:

$$e_{ij}^\nu = \begin{cases} 0 & \text{if at the } j\text{-th set of input sequence the object response that is in the } \nu\text{-th technical state, coincides with a reference response at the } i\text{-th output;} \\ 1 & \text{otherwise.} \end{cases}$$

An error vector is a special case of an error matrix when $l=1$. Let's represent error matrix also in the following form:

$$E^\nu = \left| E_{N-1}^\nu E_{N-2}^\nu \ldots E_j^\nu \ldots E_0^\nu \right|,$$

where

$$E_j^\nu = \left| e_{1j}^\nu \quad \ldots \quad e_{ij}^\nu \quad \ldots \quad e_{lj}^\nu \right|^T,\ j=\overline{0,N-1}\ .$$

A task solving algorithm includes steps which description is essentially a proof of the justifiability of ideas laid out as the basis of the suggested approach:

A. We shall present $E^\nu, \nu=\overline{1,M}$ matrices in a vector form using conjugation ε^ν by columns operation, in such a manner that E_j^ν transforms into $E_j^{\nu^T}$ for all $j=\overline{0,N-1}$ (the process is shown at Figure-3)

$$\varepsilon^\nu = \left| E_{N-1}^{\nu^T} E_{N-2}^{\nu^T} \ldots E_j^{\nu^T} \ldots E_0^{\nu^T} \right|, \nu=\overline{1,M}\ .$$

As a result, the vectors ε^ν take the form

$$\varepsilon^\nu = \left| e_{l(N-1)}^\nu \ e_{(l-1)(N-1)}^\nu \ \ldots \ e_{20}^\nu \ e_{10}^\nu \right|, \nu=\overline{1,M}\ .$$

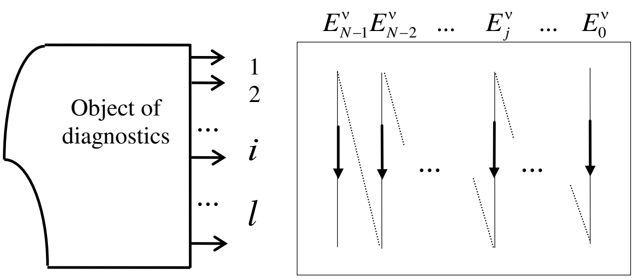


Figure-3. Principle of vector formation ε^ν

B. We shall search for a polynomial $\xi_0(x) = x^n + C_1 x^{n-1} + ... + C_n$, of degree n that is not a divider of polynomials

$$e^{\nu}_{l(N-1)} + e^{\nu}_{(l-1)(N-1)} \cdot x + ... + e^{\nu}_{20} \cdot x^{(lN-2)} + e^{\nu}_{10} \cdot x^{(lN-1)}$$

of vectors $\varepsilon^{\nu}, \nu = \overline{1, M}$.

The polynomial $\xi_0(x)$ is searched for by simple enumeration, starting from the simplest polynomial $x+1$ of degree $n=1$ until the required nondivisibility condition is met.

C. We construct for the polynomial $\xi_0(x)$ an accompanying matrix

$$A_{\xi_0(x)} = \begin{vmatrix} C_1 & C_2 & ... & C_{n-1} & C_n \\ 1 & 0 & ... & 0 & 0 \\ 0 & 1 & ... & 0 & 0 \\ 0 & 0 & ... & 1 & 0 \end{vmatrix}$$

and a column vector $B = \begin{vmatrix} 1 & 0 & ... & 0 \end{vmatrix}^T$ which fully characterizes a single channel LSM. It is evident that the accompanying matrix $A_{\xi_0(x)}$, which sets links between memory elements, describes an LSM, to which a feedback shift register corresponds.

At that, it should be remembered that $\xi_0(x)$ is a characteristic polynomial of $A_{\xi_0(x)}$ matrix, i.e. $\xi_0(x) = \det\left|A_{\xi_0(x)} + x \cdot \mathrm{I}\right|$. A single channel LSM feedback polynomial $g(x) = 1 + C_1 x + ... + C_n x^n$ is related to $\xi_0(x)$ as follows

$$g(x) = \xi_0\left(\frac{1}{x}\right) x^n.$$

D. We compute the characteristic matrices of the l-th channel analog of a single-channel LSM (for $l = 1$ the equalities $\overline{A} = A$ and $\overline{B} = B$ are true), which possesses completely the same properties as the single-channel LSM:

$$\overline{A} = A^{l}_{\xi_0(x)},$$

$$\overline{B} = \left| A^{l-1}_{\xi_0(x)} \cdot B \quad ... \quad A_{\xi_0(x)} \cdot B \quad B \right|.$$

The detailed argumentation of these relations is given in [8]. Matrices C and D are of no principal significance for signature analysis and are not considered here.

E. We shall synthesize an l-channel LSM which is described by the characteristic matrices

$\overline{A} = \left\|\overline{a}_{ij}\right\|_{n \times n}$ and $\overline{B} = \left\|\overline{b}_{ij}\right\|_{n \times l}$,

that will be an SA with the required properties.

Example. The complete verification test for double digital selector-**multiplexor** SN74153N includes the following sets:

$$H_8 = \begin{array}{c} \\ a \\ b \\ c \\ d \\ e \\ f \end{array} \begin{array}{cccccccc} Y(0) & Y(1) & Y(2) & Y(3) & Y(4) & Y(5) & Y(6) & Y(7) \\ \hline 0 & 0 & 1 & 1 & 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 0 & 0 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 1 & 0 \end{array} \begin{array}{c} \\ \rho_1 \\ \rho_2 \\ \rho_3 \\ \rho_4 \\ \rho_5 \\ \rho_6 \end{array}.$$

Let's build a signature analyzer for SN74153N that detects 18 error vectors conditioned by 22 single constant faults:

1. 10000000	10. 00110011
2. 01000000	11. 11001100
3. 00100000	12. 00000110
4. 00010000	13. 00001111
5. 00001000	14. 01100000
6. 00000100	15. 00010010
7. 00000010	16. 01001000
8. 00000001	17. 10010110
9. 11110000	18. 01101001 .

The complete DO test is built using the Rot d-algorithm, and these error vectors are obtained using digital simulation with introduction of possible faults [10].

So, we find a characteristic polynomial $\xi_0(x) = x^4 + x + 1$, to which a feedback polynomial $g(x) = 1 + x^3 + x^4$ corresponds, and build a matrix

$$A_{\xi_0(x)} = \begin{vmatrix} 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{vmatrix}.$$

ARPN Journal of Engineering and Applied Sciences

Using matrices $\overline{A} = A_{\xi_0(x)}$ and $\overline{B} = \left|1 \quad 0 \quad \ldots \quad 0\right|^T$, we build a single-channel SA (Figure-4) that detects all error vectors caused by the faults from the postulated class without exceptions.

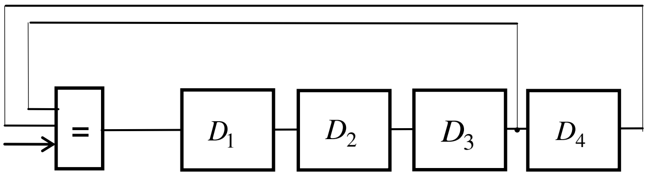
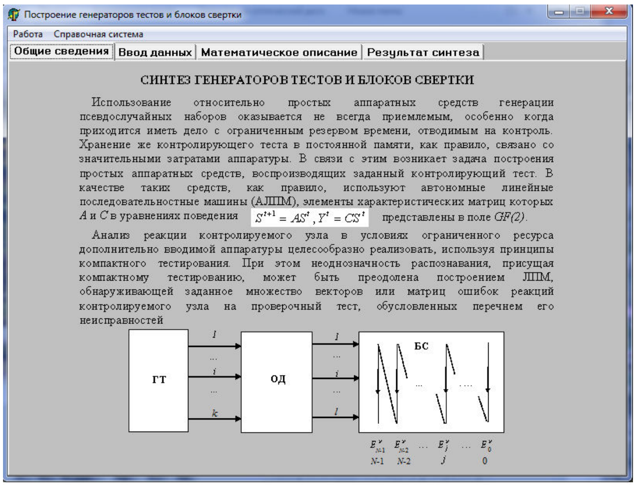


Figure-4. Signature analyzer for SN74153N.

VISUALIZATION OF A SIGNATURE ANALYZER OPERATING PROCESS

The software implementation of mathematical models of DO with arbitrary configuration and structure (Figure-5), which was developed by the author in the DELPHI 7.0 programming environment using the hypertext help systems on-line documentation HTML Help Workshop, confirms the validity of the functioning of the developed algorithms. Step by step observation of error vectors or error matrix detection process in the software model allows assuring visually that the terminal state of SA memory elements differs from the null state, i.e. $R_{er} \neq 0$.

Screen forms of SA synthesis for final results for digital networks derived using the software model are shown at Figure-6 for illustration purposes.



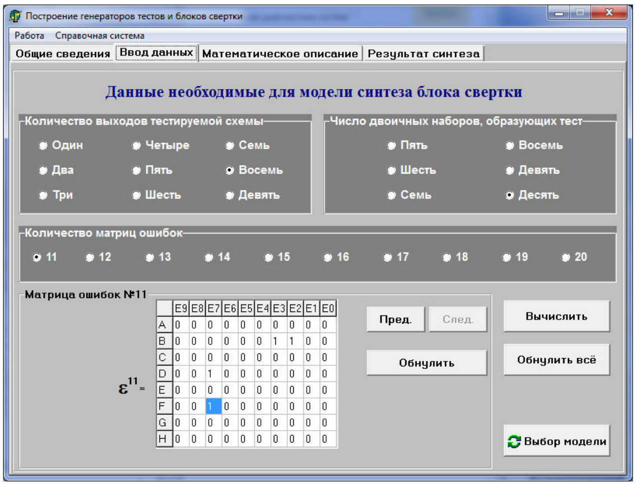
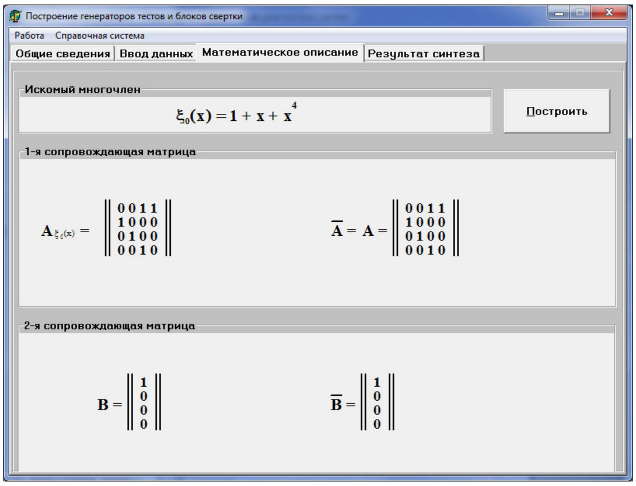
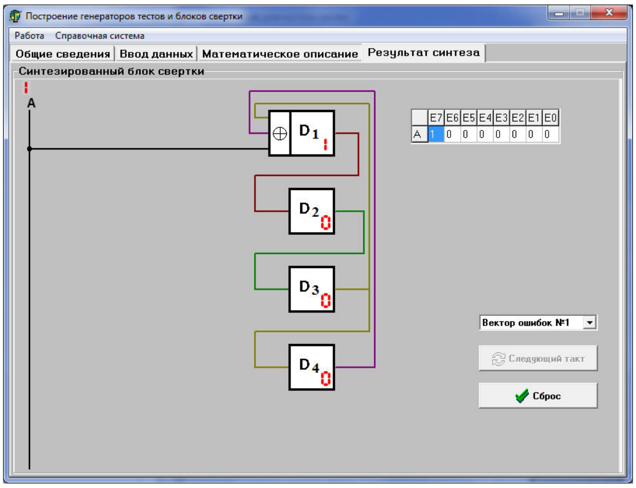


Figure-5. Screen forms of a convolver (SA) software model.





a)

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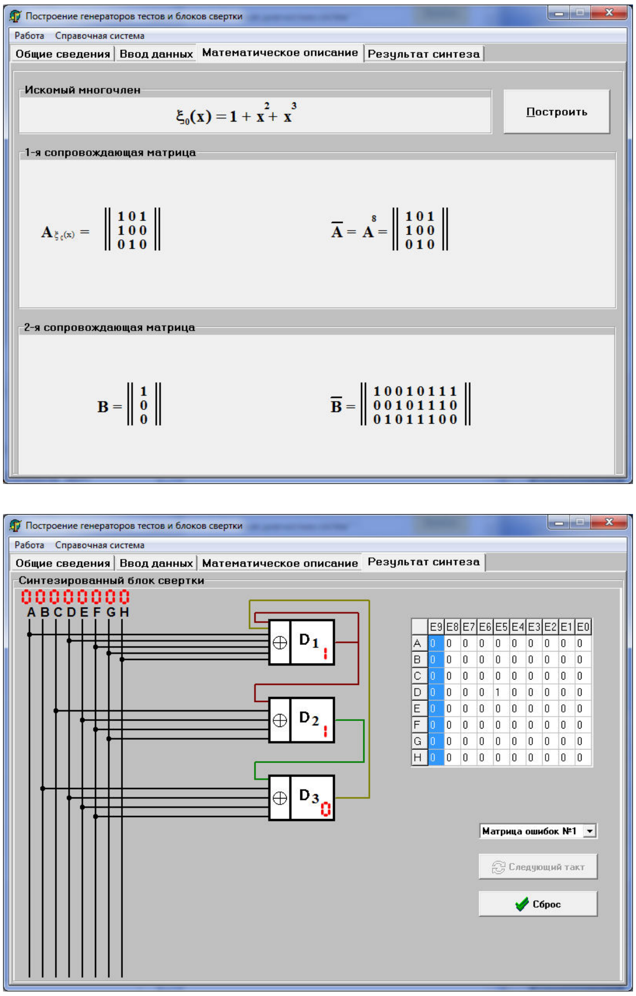

b)

Figure-6. Results of the synthesis of a signature analyzer structure:
a - single-channel SA; b - multi-channel SA

CONCLUSIONS

Thus, the algorithm developed for building a signature analyzer that detects all faults from the postulated class permits synthesis of single-channel and multi-channel LSM structures that are simple in implementation, and free from ambiguity in identification of the technical state of diagnostics objects.

Furthermore, technical implementation of a diagnostics process using signature analysis with required properties of complex digital systems becomes fairly simple. This fact allows decreasing substantially the requirements for testing staff proficiencies, and to reduce significantly the total tests cost.

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