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TESTABLE LOGICAL CIRCUIT OF A BINARY NONRESTORING ARRAY DIVIDER

Abstract. In the information processing systems LSI with regular structure (adders, subtractors, array multipliers, array dividers and so on) perform increasable part. A testable functional-logical circuit of a binary nonrestoring array divider has been elaborated. The circuit being represented possesses a fault detection test of the length of three and a small hardware complexity.

Keywords: logical circuits with regular structure, stuck-at fault, fault detection test.

It is easier to design testable digital integrated circuits with a regular structure, including adders, multipliers, subtractors, dividers, and various memory circuits, than integrated circuits with an irregular structure. The article [1] presents a testable functional-logical circuit of a binary nonrestoring array divider with a fault detection test with a sequence length 4 or 5 for single stuck-at faults. However, its implementation requires a significant amount of hardware resources, which is a major flaw. This article proposes a testable functional-logical circuit of a binary nonrestoring array divider with a fault detection test with a sequence length 3 of the same fault class and with less hardware complexity.

Layers of 1-bit adders combined within each layer into parallel adder with sequential carry are the basis of this circuit. At the same time, the construction of a testable 1-bit adder circuit that underlies the multi-bit adder of each layer is based on the representation of the sum S and carry P functions of a full 1-bit adder as polynomials dual to the Zhegalkin polynomials [2, P. 24] (since the sum S and carry P functions are self-dual) and also on the fact that these polynomials for sum S and carry P functions of a 1-bit adder are simple:

$$\begin{aligned} P &= (a \vee b) \odot (a \vee p) \odot (b \vee p), \\ S &= a \odot b \odot p, \end{aligned} \quad (1)$$

where a and b are the values of the original 1-bit operands; p and P are the values of the input and output carry signals, respectively, S is the value of the sum signal, $\vee$ is the symbol of the disjunction operation, $\odot$ is the symbol of the biconditional operation (equivalence).

The formula for the carry function P from (1) can easily be converted to convenient form:

$$P = (a \vee b) \odot [p \vee (a \odot b)] = (\overline{a \vee b}) \odot [\overline{p \vee (a \odot b)}]. \quad (2)$$

Then the testable logical circuit of the 1-bit adder can be implemented in a logical basis consisting of NOR and EQUIVALENCE two-input gates. This diagram is shown in (Fig. 1). At the same time, a rather simple schematic diagram of EQUIVALENCE gate on MOS transistors, containing only 3 transistors [3, P. 196], is known. This scheme is shown in (Fig. 2). The fault detection test for the 1-bit adder circuits in the selected basis for all single stuck-at faults contains 3 vectors and is described in table shown in (Fig. 1).

The testable n -bit (n is a positive integer) circuit of the binary adder of each layer of the nonrestoring array divider is composed of n testable circuits of a full 1-bit adder connected in a regular manner, i.e. by connecting the carry output of i -th circuit with the carry input of $(i+1)$ -th circuit, where $1 \leq i \leq n-1$.

This circuit diagram is shown in (Fig. 3). A fault detection test for a testable circuit of n-bit binary adder

for all its single stuck-at faults is conducted by simply iterating the test shown in (Fig. 1).

Figure 1. Testable 1-bit adder circuit and its fault detection test

Figure 2. Schematic of EQUIVALENCE gate in MOS transistors

p_1	b_1	a_1	b_2	a_2	b_3	a_3	...	S_1	S_2	S_3	...
0	1	0	1	0	1	0	...	1	1	1	...
0	0	0	0	0	0	0	...	0	0	0	...
1	0	1	0	1	0	1	...	0	0	0	...

Figure 3. Testable n-bit adder circuit and its fault detection test

	u	Q ₀	D ₁	D ₂	D ₃	D ₄	N ₁	N ₂	N ₃	N ₄	N ₅	N ₆	N ₇	Q ₁	Q ₂	Q ₃	Q ₄	R ₁	R ₂	R ₃	R ₄	R ₅	R ₆	R ₇
1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1
2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0

Figure 4. Testable circuit of 4 x 4-bit nonrestoring array divider and its fault detection test

The testable functional-logical circuit of the $n = 4$ is shown in (Fig. 4). In Fig. 4 nonrestoring $n \times n$ bit array divider for array with $(N_1, N_2, N_3, N_4, N_5, N_6, N_7)$ and (D_1, D_2, D_3, D_4)

represent the dividend and the divisor, respectively. N_1 and D_1 are the respective sign bits. (Q_1, Q_2, Q_3, Q_4) are the quotient bits. $(R_1, R_2, R_3, R_4, R_5, R_6, R_7)$ are the remainder bits. The value of Q_{i-1} determines whether subtraction or addition should be performed in the i th row. Since the initial subtraction must always be carried out, $Q_0 = 1$. The considered circuit contains seven additional two-input EQUIVALENCE gates and one additional input u . In this case, in the operating mode, the logical (1) signal is fed to the input u . The fault detection test for all single stuck-at faults of this circuit contains 3 vectors and is described in table shown in (Fig. 4).

The fault-detection test for the general case also contains 3 vectors and is constructed as follows:

- the sequence 1,0,0 ($j \in \{1, 2, \dots, n\}$) is fed to each D_j input;
- the sequence 1,0,0 ($i \in \{1, 2, \dots, 2n-1\}$) is fed to each N_i input;
- the sequence 1,0,1 is fed to Q_0 input, and the sequence 0,1,1 is fed to u input.

It is easily seen that in general the testable $n \times n$ bit nonrestoring array divider contains $2n-1$ additional two-input EQUIVALENCE gates. The testable circuit found in [1] requires significantly bigger amount of hardware resources for its implementation than the proposed testable circuit.

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