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Fault self-repair strategy based on evolvable hardware and reparation balance technology

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Abstract In the face of harsh natural environment applications such as earth-orbiting and deep space satellites, underwater sea vehicles, strong electromagnetic interference and temperature stress, the circuits faults appear easily. Circuit faults will inevitably lead to serious losses of availability or impeded mission success without self-repair over the mission duration. Traditional fault-repair methods based on redundant fault-tolerant technique are straightforward to implement, yet their area, power and weight cost can be excessive. Moreover they utilize all plug-in or component level circuits to realize redundant backup, such that their applicability is limited. Hence, a novel self-repair technology based on evolvable hardware (EHW) and reparation balance technology (RBT) is proposed. Its cost is low, and fault self-repair of various circuits and devices can be realized through dynamic configuration. Making full use of the fault signals, correcting circuit can be found through EHW technique to realize the balance and compensation of the fault output-signals. In this paper, the self-repair model was analyzed which based on EHW and RBT technique, the specific self-repair strategy was studied, the corresponding self-repair circuit fault system was designed, and the typical faults were simulated and analyzed which combined with the actual electronic devices. Simulation results demonstrated that the proposed fault self-repair strategy was feasible. Compared to traditional techniques, fault self-repair based on EHW consumes fewer hardware resources, and the scope of fault self-repair was expanded significantly.

1. Introduction

With the development of the information technology and the electronic systems, which are mainly composed of large-scale integrated (LSI) and the very large scale integrated (VLSI) circuit with the field programmable gate array (FPGA) as their core component, are widely used in electronic equipments.[1–4] Facing complex nature environment, such as dust, high and low temperature, strong electromagnetic scenes, the performance of digital integrated circuit in these electronic systems

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will be affected. The electronic systems will degrade, malfunction, or even cause significant casualties and property losses.[1–3]

After being designed and produced, the traditional circuit structure of electronic equipment is fixed, and cannot be changed.[1–3] It is simple to implement the traditional redundant fault-tolerant technology based on fault self-repair technology, but the implementation cost is high and could not achieve redundancy backup for all plug-in or component level circuits, which limits its application in fault self-repair.[5–7] It is very important to further improve the survivability of the electronic system in harsh environments, and ensure the digital system could work normally and lastingly.[8,9] New methods of fault self-repair needs to be explored to solve these problems.

Based on evolvable hardware (EHW) and reparation balance technology (RBT), a new fault self-repair technology is proposed. The evolutionary algorithm (EA) is used as tool of combinational optimization and global search of EHW.[10–12] Through EHW evolves simulation expecting function of the circuit and the system structure, and makes full use of the advantages of the technique of EHW, such as robustness, self-organizing, self-adaptive.[11–15] By making full use of the fault signal, a correcting circuit through EHW technology is found to realize the balance of compensation of the fault signal output. This technology of fault self-repair strategy is different from the existing references.[1,4,7,8,15] It can realize self-repair of multi-cell circuit fault dynamically, and is not limited to a certain kink of circuit.

2. Basic theory of EHW and RBT

2.1. Basic theory of EHW

EA is used as tool of combinational optimization and global search of EHW.[11,14–16] The circuit and system structure can be obtained by simulating evolution.[15–18] The chromosome coding of EAs are the structure of the programmable devices bit string, which can find better circuit structure.[11,14,18–20] The evolution process is shown in Fig. 1.[11]

EHW has a good feature of robustness, self-organizing and self-adaptive. Its formula is Evolutionary Algorithms + Programmable Logic Devices = Evolvable Hardware,[10,11,18–20] that is EAs + PLDs = EHW.

In the field of fault self-repair, redundancy design is adopted to realize the fault self-repair in the existing references, while the application of fault self-repair based on EHW is absent.[1–3] Many references studied fault diagnosis technique and EHW separately, and their fusion applications failed to implement.[10,14] Although some references used EHW technique to realize fault self-repair, the fault self-repair mechanism was not researched clearly.[21–23]

2.2. Basic theory of RBT

RBT is defined as follows. When the circuit output response is not consistent with the expected output, the original fault output-signals can be corrected through the additional rectification circuit (RTC) in output ports, so the expected output response can be obtained.

RTC is the abbreviation of rectification circuit. It can deal the fault signal directly, and it is the core of the RBT. The examples of RTC are shown in Section 3.2.

The fault self-repair strategy based on EHW and RBT include two parts: one part is state self-repair and the other is fault self-repair. This paper mainly studies the fault self-repair.

The evolved circuits have smaller scale at present, and the divide and rule technique is usually used in evolving large scale circuits. Its main idea is that the large scale circuits are decomposed into smaller circuit, and then the decomposed circuits are evolved. The problem of evolving large scale circuits has been the hot issue home and abroad. However, it is not the core of this paper.

3. RBT model and self-repair strategy analysis

3.1. RBT model

In order to analyze the fault self-repair strategy based on EHW and RBT effectively, it is necessary to model the self-repair fault. The response of normal circuit system is shown in Fig. 2(a), the equation $Y = X \bullet H(X)$ can be gotten. "$\bullet$"is an operator, but it is not limited to additional subtraction, multiplication and division, it usually includes AND, OR, NOT, XOR, and NOR of digital circuit.

After faults appear in the system response $H(X)$, the system response will be changed from $H(X)$ to $H_1(X)$. Here our concern is whether the fault exists or not, while the specific kind of the faults is not our concern. As shown in Fig. 2(b), when the output is changed from Y to Y_1, Y_1 does not conform to the input-signal requirements of next level circuit. At this time, the fault system response $H_1(X)$ needs to be compensated and balanced. Through real-time detecting states, the faults characteristics can be recorded. According to these characteristics, the corresponding compensation balance circuit can be designed by EA, and the self-repair of fault circuit can be realized.

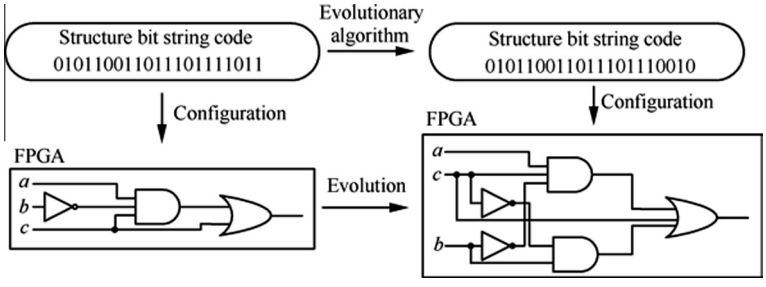

Fig. 1 Basic theory scheme of evolvable hardware.