

# A Novel Structure of Embryonics Electronic Cell Array

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*Abstract:* - Based on the classic embryonics electronic cell array structure, a novel structure of embryonic electronic cell array is proposed. The connections between cells are subdivided into local connection mode and remote connection mode. Cell is directly connected to its eight surrounding neighbor electronic cells in local connection mode. In remote connection mode, the signal between nonadjacent electronic cells transmits via the cooperation of switch boxes in electronic cells. By extending the connections between the electronic cells, the width of the switch box in each electronic cell is reduced and the length of gene configured connection is shorted with the ensuring connectivity between electronic cells. The self-repair ability of the proposed embryonics electronic cell array is verified through the simulation realization of a circuit.

*Key-Words:* - embryonics electronic cell array, local connection mode, remote connection mode, electronic cell structure

## 1 Introduction

The proposition of embryonics (embryological electronics, embryonics) [1] provides a new direction for the study of self-repairing circuit. In the recent two decades, the embryonics has been developed rapidly, and a series of hardware architecture with self-repair capabilities have been proposed under the guidance of embryonics. C. Ortega proposed the basic structure of embryonics [2]. D. Mange et al realized the embryonics with the multiplexer [3], and R.O. Chaham et al realized the embryonics with the LUT as the function unit [4]. Y. Thoma et al added routing unit with independent routing ability into embryonics, and the I/O unit was substituted for the routing unit [5, 6]. The routing and function was separated, and the routing adaptive was increased. A. Stauffer et al presented a 3D cell structure [7], and the embryonics was developed into 3D space. A.M. Tyrrell put forward honeycomb architecture of embryonics [8], and the connections between cells were enriched. DOU Yong et al proposed a bio-inspired adaptive reconfigurable hardware architecture which process data based on data tag [9]. S. Kim et al divided the embryonics into control module array and function

module array, and the neighbor cell with different state [10]. The self-repair capability was extended. WANG Youren et al proposed a new cell array structure realized online distributed fault-tolerant in-chip [11], and the 3D cell structure was researched [12].

The electronic cell array is the basis of embryonics. Although varieties of embryonics structure were proposed, the electronic cell array used in these embryonics mostly is the classic architecture. In the classic structure of electronic cell array, the connection between cells is reached via the match of the I/O unit included in each cell. Y. Thoma et al designed a separate routing unit outside electronic cell with independent routing ability [5, 6]. The global optimal routing scheme is difficult to get through distributed routing, and a long repair time is needed to re-routing in self-repair process when the scale of the circuit is large. The honeycomb structure [8] proposed by A.M. Tyrrell extensive connections between electronic cells, but the structure does not contribute to the row/column elimination self-repair. This paper presents a novel electronic cell array structure, and the connections between electronic cells divided into local connection and remote connection due to cells'

corresponding position. Adjacent cells interaction through the local connection and the nonadjacent cells interact with one another through remote connection. Connections between cells are enriched with the local connection and remote connection, and the forms of circuit realized on the electronic cell array are increased and the capacity of the embryonic is enlarged which provide a foundation for the evolution of circuit.

## 2 Structure of electronic cell array in embryonics

The electronic cell array is mainly consisting of electronic cell and the connection between the electronic cells. The connection between electronic cells is composed of I/O unit and the wire.

The connections are divided into local connection and remote connection in the proposed electronic cell array structure. With local connection, the adjacent electronic cells transfer signal to one another direct. The signals transmit through remote connection between nonadjacent electronic cells, under the cooperation of the switch box in each electronic cell and the wire. The structure of electronic cell array is illustrated in Fig.1.

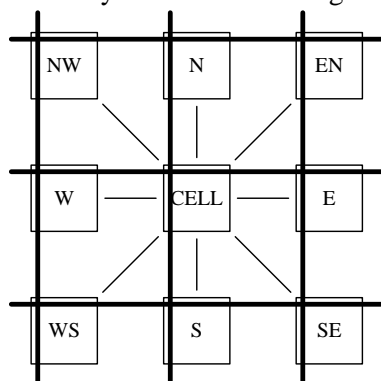


Fig.1 The connection mode in embryonics electronic cell array

In Fig.1, across the correspondingly position the neighbor electronic cells are named as S, SE, E, EN, N, NW, W and WS. The center electronic cell CELL could transfer signal to the eight neighbor electronic cells direct through the wire without a switch box. Nonetheless, the signal transmission between nonadjacent electronic cells like NW and EN could be

accomplished under the cooperation of the switch box in NW, N, EN and the wire.

### 2.1 Local Connection Mode

Local connection scheme is shown in Fig.1. The electronic cell interacts with its eight neighbors direct. The electronic cell's output signal is the neighbors' input and the neighbors' output is the electronic cell's input.

The direct connection in Fig.1 could ensure the connection between the cell and its eight neighbors, and the signal could be transferred through the direct connection. Nevertheless, this direct connection in SE, EN, NW, WS direction is difficult to repair in self-repair process. When a function circuit is realized on electronic cell array as shown in Fig.2(a), the adjacent electronic cells are connected direct. When the electronic cell in position (2, 2) is faulty, the second column is eliminated through column elimination self-repair mechanism and the role F2 is realized by the electronic cell in (2, 3). In the self-repair process, the connection between electronic cells (1, 1) and (2, 2) is replaced by the connection between electronic cells (1, 1) and (2, 3). The connection relationship should be calculated in the self-repair process, and the connection should be reconfigured according to the calculate result to accomplish the connection between electronic cells (1, 1) and (2, 3). In this self-repair process, the extra hardware is needed to calculate the connection and the complexity of the cell is increased.

The diagonal direct connection is not adapted to the row/column elimination self-repair, and in the self-repair process extra hardware is required to calculate the rerouting configuration. In order to make the local connection more suitable for the row/column elimination self-repair and reduce the complexity of the electronic cell, the direct diagonal connection is optimizing designed. The diagonal direct connection is converted to the connection between electronic cells in the same row and the connection between electronic cells in the same column, as showed in Fig.2(c). When the electronic cell in the position (2, 2)

is faulty, the second column is eliminated from the circuit with column elimination self-repair, and the electronic cell in the second column become “transparent”. The electronic cells in third column express the gene in the correspond cells of the second column, and the function of electronic cell in position (1, 2) and (2, 2) is implemented by the electronic cell in position (1, 3) and (2, 3). The connection of the electronic cell in position (1, 2) and (2, 2) is held, and the connection between electronic cell with the function F1 and F4 is maintained, as showed in Fig.2 (d). This process does not need recalculation of connection between the electronic cells, and the complexity of the electronic cell is reduced.

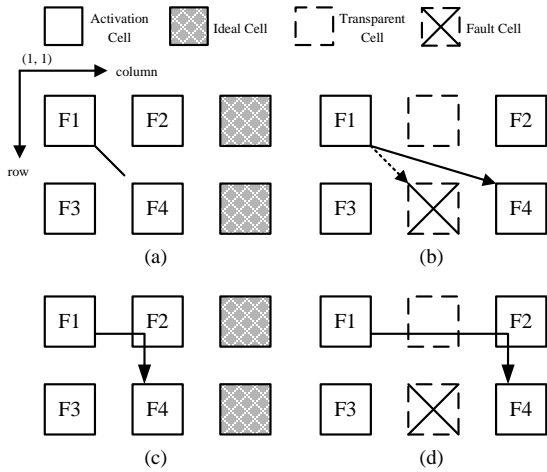


Fig.2 The self-repair for diagonal connection

The local connection after optimizing design is shown in Fig.3.

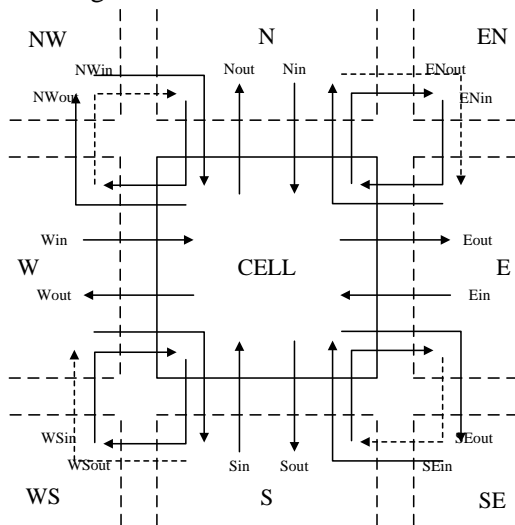


Fig.3 The local connection mode of electronic cell

The electronic cell could be connected to the input and output of its eight neighbors direct through the local connection shown in Fig.3, and the

connection relationship between the adjacent cells is unchanged in the self-repair process through row/column elimination mode.

## 2.2 Remote Connection Mode

Signal transfer between adjacent electronic cells can be accomplished through local connection, but in the actual circuit, only the connection between the adjacent electronic cells cannot meet circuit functional requirements, and the connection between nonadjacent electronic cells is also required.

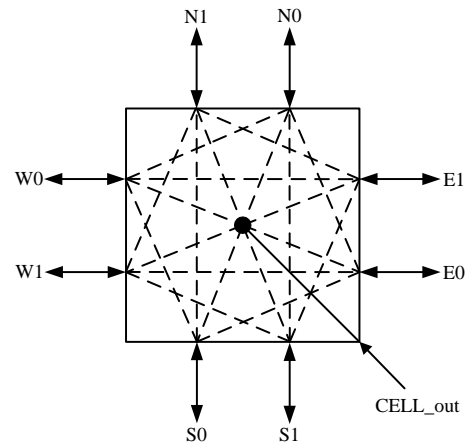


Fig.4 The structure of switch box in remote connection

A switch box is employed to remote connection between nonadjacent electronic cells. The structure of switch box is shown in Fig.4. S0, S1 is connected to the south direction, W0, W1 is connected westward direction, N0, N1 is connected northward direction and E0, E1 connections to east direction. CELL\_out is the functional output of the electronic cell. Every direction can be connected to the other three directions and the cell’s functional output through the switch box and the four direction of the switch box can served as an input of the cell’s functional circuit.

Every electronic cell in the electronic cell array consists of a switch box for remote connection, and all the switch boxes in the electronic cell array form a connection network, as showed in Fig.1. Through the cooperation of several switch boxes in the network, any two electronic cells in the array can be attached.

### 3 The self-repair method of the electronic cell array

Row/column elimination is the mostly used self-repair method for electronic cell array. And the self-repair method used for the proposed electronic cell array is column elimination.

The self-repair mechanism is closely linked to the structures of electronic cell and electronic cell array. In order to realize the column eliminated from the electronic cell array, the cell's transparent mode is designed.

#### 3.1 Electronic Cell's Transparent Mode

Electronic cell transparent mode refers to the function of the faulty cell is eliminated from the electronic cell array under the control of external signal and the cell becomes transparent state for its surroundings. The transparent mode is the basis for an array in self-repair process.

Under the control of the transparent control signal, the input and output of an electronic cell are connected direct, and the inputs are connected to the outputs of the electronic cell without the process of the function module. And the function module of the electronic cell is eliminated from the application. The structure of an electronic cell with transparent mode is illustrated in Fig.5.

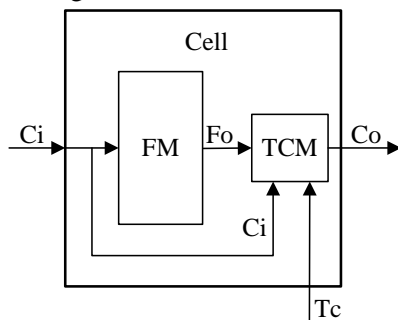


Fig.5 The structure of electronic cell with transparent mode

In Fig.5, FM is the functional module of the electronic cell, TCM is the transparent mode control module,  $C_i$  is the electronic cell's input,  $T_c$  is the transparent mode control signal,  $C_o$  is the electronic cell's output signal, and  $F_o$  is the output of the cell's

functional module.

The function pseudo-code of the transparent mode control module is as follows:

if ( $t_c = \text{False}$ )	$C_o = F_o;$
else	$C_o = C_i;$

In normal mode, the electronic cell's transparent mode control signal  $T_c$  is false, and the cell's output is the output of the cell's functional module. When a fault is occurring, the signal  $T_c$  turns to be true, and the cell's output is the input without the process of the functional module. The cell's functional module turns to transparent.

For electronic cell's surrounding environment, the functional unit and the switch box of the electronic cell in transparent mode do not exist, and only direct connection is reserved.

#### 3.2 Column Elimination Self-Repair

In column elimination self-repair, the failing of one cell provokes the elimination of the corresponding row/column, and the function of the column with the faulty cell and the rows/columns after will be backward-shifted, until making use of a spare column. Column elimination self-repair mechanism is simple, and the hardware cost is low.

The BIT module detects the electronic cell's state in the real time. When a fault is detected, the BIT module sends an electronic cell fault signal to the repair control module, and then repair control module sends a transparent mode control signal to the column with the fault electronic cell. Under the control of transparent mode control signal, all electronic cells in the column will be set to be transparent state. The self-repair process is accomplished through column elimination.

### 4 Structure of electronic cell

Based on the classic electronic cell proposed in [2], the structure of electronic cell is designed according to the need of the proposed structure of electronic cell

array and the self-repair mechanism. The designed structure of electronic cell is indicated by Fig.6.

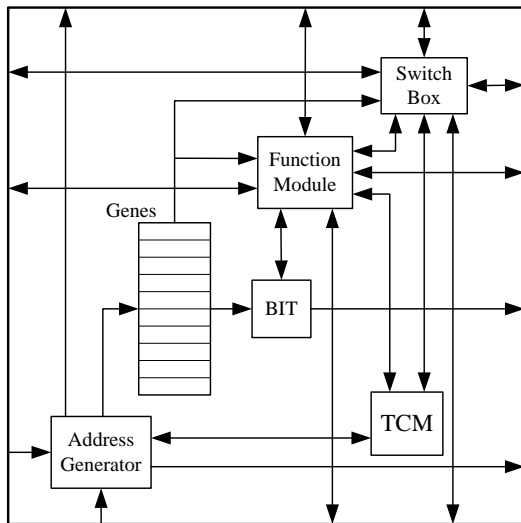


Fig.6 The structure of electronic cell

An electronic cell is composed of Address Generator, Genes, Build-In-Test (BIT), Function Module, Switch Box and Transparent Control Module (TCM), and the previous designed structure [13] of the Address Generator, Genes and BIT is used and not discussed here.

The structure of Switch Box is shown in section 1.2, and the structure of TCM is addressed in section 2.1.

### 4.1 Function Module

Function Module is at the heart part of the electronic cell to implement the circuit's function. Various functions of a certain size can be achieved by Function Module through expressing different genes.

The 4-input look-up table (4-LUT) is invoked as the main part of the Function Module in this design. Any logic function with no more than four inputs can be achieved by the 4-LUT with corresponding configuration.

The block diagram of the Function Module in this design is indicated by Fig.7 (b). Input is the input of the Function Module, O is the output of the Function Module, I1, I2, I3, I4 is the input of the 4-LUT, O0 is the output of the 4-LUT and the input of the Flip-Flop, O1 is the output of the Flip-Flop. C1, C2, C3, C4 is the control signal of the input. FC0 is

the control signal for the LUT configuration. FC1 is the control signal for the delay, and clk is the clock signal.

The input of the Function Module includes the signal from neighboring electronic cells in local connection and the signal from nonadjacent electronic cells in remote connection. The input signals are chose as the input of LUT by 16-1 multiplexer (MUX) under the control of select signals.

FC0 is configuration information for the LUT, and it determines the logic function of the LUT. The output of LUT O0 can be obtained according to the LUT's input and function configuration. O0 is the input of a Flip-Flop whose output is O1. The O0 and O1 are chosen as the output of Function Module under the control of FC1. The Flip-Flop provide a basis for the implemented of sequential circuits.

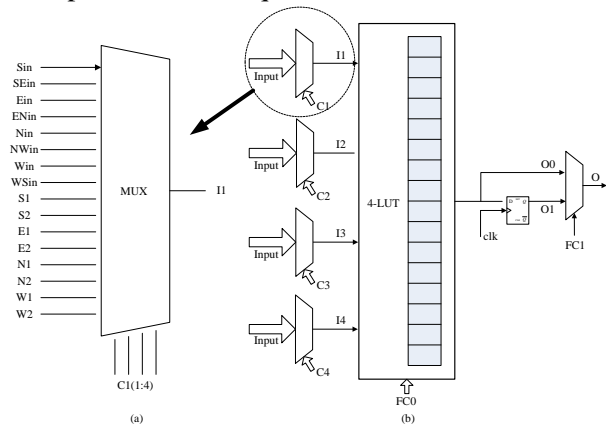


Fig.7 The frame of function module

### 4.2 Gene Configuration of Electronic Cell

The gene configuration is the soul of electronic cell, and different gene determines the unique connection and function. With different genes are expressed in different electronic cells of electronic cell array, the target circuit can be formed, and pre-designed function can be achieved.

In this design, the electronic cell gene includes LUT function configuration, delay select configuration, LUT input selection configuration, switch box configuration. The function and length of each part in gene are shown as Table 1.

The length of the utilized gene is 57. The bits of 0 to 15 are the LUT's function configuration information. The bits of 17 to 32 are the LUT's input

select figuration. The bits of 17 to 20 are the input select for I1. The bits of 21 to 24 are the input select for I2. The bits of 25 to 28 are the input select for I3. The bits of 29 to 32 are the input select for I4. The bits

of 33 to 56 are the switch box configuration information, wherein bits of 33 to 35 is the configuration for S0 direction, bits of 36 to 38 is the

Table 1 The assign of the gene in Electronic Cell

Gene	56-33	32-17	16	15-0
Function	Switch box control signal	Input of LUT select control signal	Delay configuration	Configuration for function of LUT
Length	24 bits	16 bits	1 bit	16 bits

configuration for S1 direction, bits of 39 to 41 is the configuration for E0 direction, bits of 42 to 44 is the configuration for E1 direction, bits of 45 to 47 is the configuration for N0 direction, bits of 48 to 50 is the configuration for N1 direction, bits of 51 to 53 is the configuration for W0 direction, and bits of 54 to 56 is the configuration for W1 direction.

WSin are local connection port. x\_in and y\_in are ports for input address. x\_out and y\_out are ports for output address. CellFault is the output port for electronic cell's fault signal, and the fault signal can be transferred outside from the port. clk is the clock signal for the electronic cell. TC is the control signal for transparent mode.

### 5 The simulation realization of electronic cell array

Being dependent on the design of the electronic structure, the electronic cell is designed and simulated in the Xilinx ISE Design Suite 12.2. Every part of the electronic cell is described using Verilog language, and then the electronic cell module is created with the Create Schematic Symbol feature in ISE. The created electronic cell module is shown in Fig.8.

The electronic cell designed can be connected to one another, and an electronic cell array can be formed with multi-cell. An electronic cell array with size of 2\*3 formed with six electronic cells is shown as Fig.9.

In the electronic cell array shown as Fig.9, the SEout signal from electronic cell (1, 1) can be transferred to the NWin of electronic cell (2, 2) through W2S\_W and W2S\_S of the electronic cell (1, 2), and the signal transmission from electronic cell (1, 1) to electronic cell (2, 2) can be achieved. Through the E2N\_E and E2N\_N of electronic cell (2, 1), the NWout signal of electronic cell (2, 2) can be send to the SEin of electronic cell (1, 1), and the signal transmission from electronic cell (2, 2) to electronic cell (1, 1) is completed. The signal transmission between electronic cell (1, 1) and (2, 3) can be achieved through the remote connection ports of electronic cells (1, 2) and (1, 3).

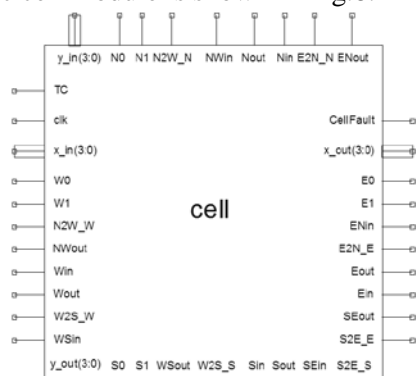


Fig.8 The electronic cell module

In the electronic cell, S0, S1, E0, E1, N0, N1, W0 and W1 are remote connection port. WSout, W2S\_S, Sin, Sout, SEin, S2E\_S, S2E\_E, SEout, Ein, Eout, E2N\_E, ENin, ENout, E2N\_N, Nin, Nout, NWin, N2W\_N, N2W\_W, NWout, Win, Wout, W2S\_W and

### 6 The experiment and analysis

To verify the advantage of the self-repair ability of proposed electronic cell array, a circuit is realized on the electronic cell array. Based on the electronic cell array, a logic circuit with 7 inputs and 1 output is realized. Part of the truth table is given in Table 2.

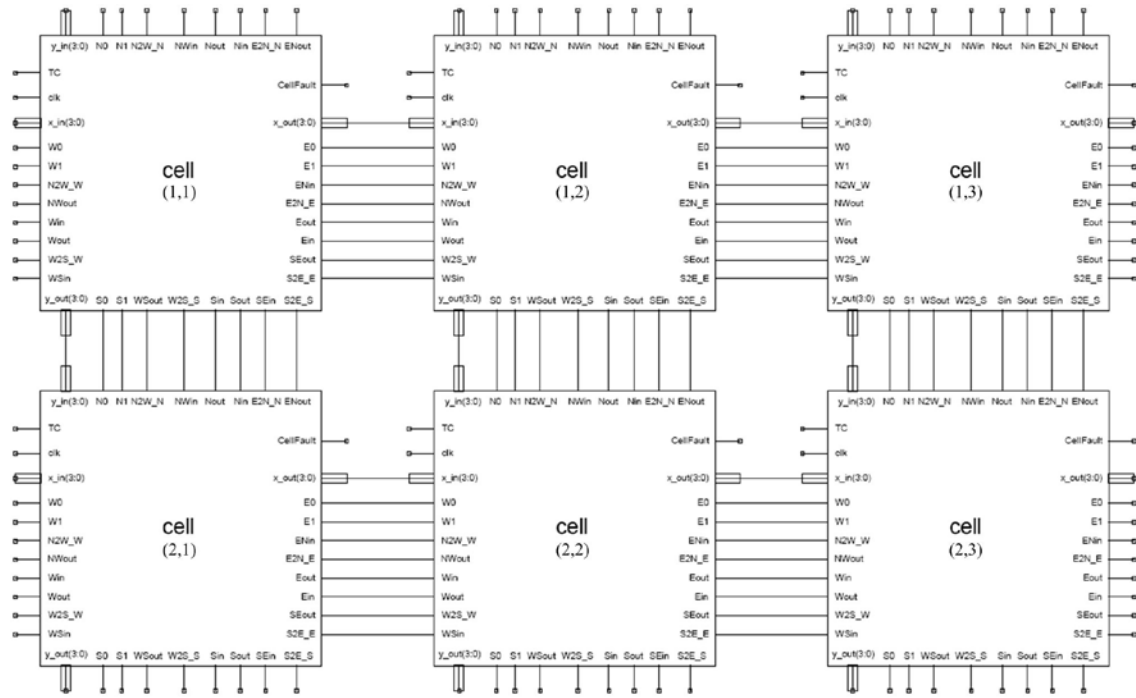


Fig.9 The structure of electronic cell array with size of 2\*3

Table 2 Part of the truth table of a circuit

Input							Output
A	B	C	D	E	F	G	FuncOut
1	1	1	0	1	0	0	0
0	0	0	1	1	0	0	1
1	0	0	1	1	0	0	0
0	1	0	1	1	0	0	1
1	1	0	1	1	0	0	0
0	0	1	1	1	0	0	1
1	0	1	1	1	0	0	1

To realize the circuit, an electronic cell array with size of 3\*4 is built up with 12 electronic cells, and the configuration of each electronic cell is given in table 3. In the realizing example, only the local connection is used, so the low 32 bits of each electronic cell's configuration is listed, and the extra

bits of the configuration are all 0.

The circuit under the configuration as Table 3 is simulated in ISim M63c, and parts of its function are tested. The input, output, transparent mode control signal and the available column number of the electronic cell array are watched in the simulation, and the simulation result is shown in Fig.10.

Table 3 The expressed gene of each electronic cell

	C1	C2	C3	C4
R1	00EC2D 2D	00000000	00000000	00000000
R2	EECA7C 7C	EECAC5C 5	CCCC808 0	CCCC808 0
R3	CCA887 87	00000000	00000000	00000000

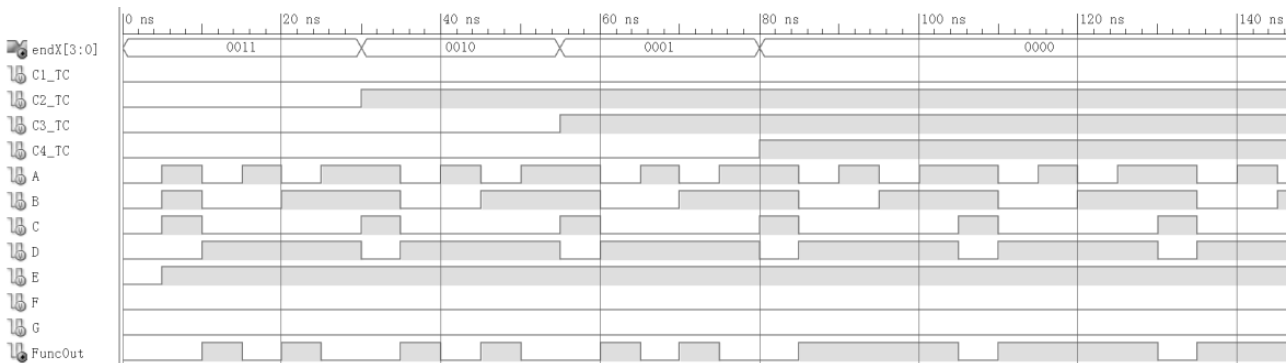


Fig.10 The self-repair realization of a circuit

From the simulate result we can see that, when a fault occur at the electronic cell in the second column

at 30ns, the transparent mode control signal of the second column C2\_TC is activated, and the second

column is elimination from the electronic cell array. The column of effective electronic cell number is three (the number is counted from zero) and the function of the circuit is kept. At 54ns, an electronic cell in column three is faulty, and the signal C3\_TC is activated, and then the third column of the electronic cell array is eliminated. The column of health electronic cell in the array number is two, and the circuit's output FuncOut is normal. At 80ns, an electronic cell in column four is faulty, and the signal C4\_TC is activated and the fourth column is eliminated. At this time, the column of health electronic cell left number is one, and it's not enough to accomplish the function of the target circuit, and then the self-repair process is failed and the circuit's output signal FuncOut is wrong.

From the simulation result we can see that, the circuit realized on the proposed electronic cell array has the ability to self-repair and the self-repair process is fast.

## 7 Conclusion

A new structure of electronic cell array is proposed, and the connection mode between electronic cells is increased with the local connection and remote connection. The flexibility of the circuit form realized on the electronic cell array is improved. The width of the IO routing unit is reduced through local connection, and the length of the desired gene is reduced.

The electronic cell is designed and simulated, and a specific circuit is implemented based on the proposed electronic cell array. The self-repair ability is verified through the simulation experiment.

In the simulation experiment, the scale of the circuit is small, and the memory desired to store the gene in electronic cell is less. But for the larger scale circuit, the memory needed to store the gene will be very huge. Out next research focus is that how to decrease the storage gene in electronic cell. In addition, how to determine the configuration information of every electronic cell in the electronic

cell array for large-scale circuits, it will be the direction of the next phase of our research.

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