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Design of Automatic Line Fault Injection Equipment and Verification of BIT Detection Capability

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To verify the BIT detection capabilities of electronic products, an automatic line fault injection equipment is designed. This paper shows the overall function and the overall structure of the equipment. Based on the function and the overall structure, the communication protocol between the computer and the fault injection equipment is designed. The BIT detection capability verification process based on the equipment is also given. Finally, a case of fault injection experiments to an environmental control system is given, and the result shows that the equipment is available and effective.

1. Introduction

The line fault injection techniques can be used to verify the BIT detection capability of electronic products by injecting types of faults into products in laboratories. The fault type of electronic devices is complex, and the length of fault duration time has great impact on product function (Liu et al., 2007). Existing fault injection equipments for electronic products have some defections: little injectable fault types, poor universalization and complex injection process(Shi et al., 2007). In addition, few existing fault injection equipments take fault duration time into account (Correia et al., 2009).
In view of the above problems, this paper introduces an automatic line injection equipment: with the equipment, we need only input corresponding commands through PC software, and the equipment can finish the fault injection process automatically. The communication (Wei-Chih Hsu et al., 2012)between PC and the equipment adopts the USB interface technology, and the core processing module of the equipment adopts the FPGA technology (Witting et al., 1996). These two technologies make the equipment universal, highly integrated and portable. Finally, a case of fault injection experiment is given, and the result shows that the equipment is available and effective.

2. Overall function

The fault injection equipment has two operating modes: test mode and work mode. Its overall function framework is shown in Figure 1.

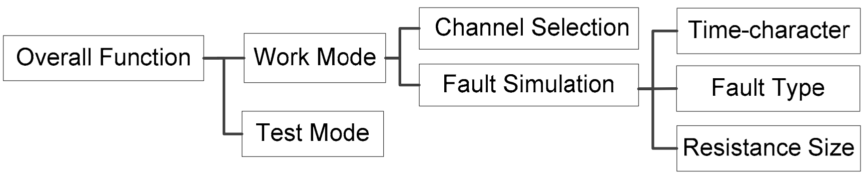

Figure 1: Overall function framework of the equipment

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2.1 Work mode

The work mode is the fault injection process. It contains two main parts: channel selection and fault simulation.

The channel selection refers to selecting the expected signal line from all the signal lines connected to the equipment. The equipment can connect 32 signal lines at most and only one signal line can be selected to inject a fault at a time.

The fault simulation function is very important. To inject a fault into an electronic product, we have to simulate the fault at first. And to simulate the fault accurately, we have to obtain the type and the time-character of the fault . For some types of faults, we also have to know the resistance sizes needed in fault simulation.

- This fault injection equipment can simulate six types of faults, as is listed below:
- Open circuit fault: disconnect a connecting signal line;
- Output error fault: connect a signal line to an outside excitation source;
- High voltage fault: set the input or output port of a signal line to high voltage;
- Low voltage fault: set the input or output port of a signal line to low voltage;
- Resistor fault1: add a series resistance to a signal line;
- Resistor fault2: connect a series resistance between a signal line and the GND;
- Faults can be divided into transient faults, intermittent faults and permanent faults according to time-character.
- A transient fault is a fault that no longer present if power is disconnected for a short time.
- An intermittent fault is a malfunction of a device or system that occurs at intervals.
- A permanent fault is a fault that does not disappear with time.
- If we want to inject resistor faults into electric products, we have to adjust the resistors connected to the circuit. Otherwise, the injected electronic products may be burnt out.

3. Overall structure

Based on the overall function, the overall structure of the fault injection equipment is designed, as is shown in Figure 2.

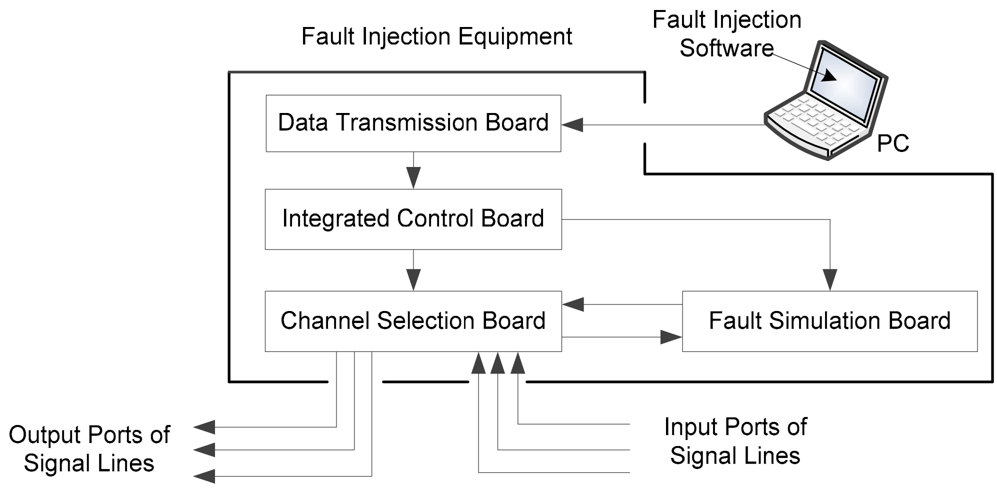

Figure 2: Overall structure of the equipment

In Figure 2, the testers input the fault injection related information through the fault injection software . The software converts the information into binary commands in accordance with the communication protocol and sends the commands to the fault injection equipment.

According to the hardware structure, the equipment is divided into four parts: the data transmission board, the integrated control board, the fault simulation board and the channel selection board.

3.1 Data transmission board

The data transmission board is made up of a USB interface chip and the corresponding peripheral circuits (Xian et al., 2012). It receives commands sent by PC through USB interface and then sends these commands to the integrated control board through PE pins, enabling the communication between the PC and the fault injection equipment.

3.2 Integrated control board
The integrated control board is made up of an FPGA chip and the corresponding peripheral circuits (Ravishankar, 2012). It receives the data sent by the data transmission board through FPGA input pins and then analyzes these commands. Finally, it converts the analysis results into voltage values of the output ports. Each output port of the integrated control board is connected to a relay driver circuit of the fault simulation board and the channel selection board. If an output port has a high level voltage, the corresponding relays will be closed. Or, they will be open. The integrated control board takes the control of the fault simulation board and the channel selection board by changing the voltage values of the output ports.

3.3 Fault simulation board
The fault simulation board is made up of 48 relays and the corresponding drive circuits. Its function is to simulate different types of circuit faults by changing the status of relays. The fault simulation board has been patented by the State Intellectual Property Office of PRC.

3.4 Channel selection board
The channel selection board is made up of 64 relays and the corresponding drive circuits. It can connect 32 signal lines at most. Its main function is to select the expected signal line from all the lines connected. The selected signal line will be connected to the fault simulation board.

4. Communication protocol

The communication protocol is necessary to the communication between the PC and the fault injection equipment. According to the overall function and the overall structures of the equipment, the communication protocol is designed, as is shown in Figure 3. It contains four bytes, each byte is a command.Three of the commands are injection related commands and the last one is the termination command.

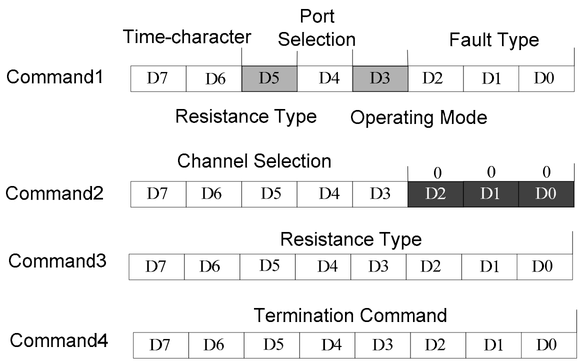

Figure 3: Communication protocol

4.1 Command1
The command1 carries five parts of information: the time-character, the resistance type, the port selection, the operating mode and the fault type.

➢ Time-character

D7 and D6 are used to determine the time-character of the fault to be injected. If D7 and D6 are both 0, the fault is a transient fault; if 0 and 1, it's an intermittent fault; if 1 and 0, it's a permanent fault.

➢ Resistance type

When we need a resistance in a fault injection process, we can choose from the internal resistances and the external resistances. And one bit is enough to determine the resistance type. If D5 is 0, it means choosing an external resistor. Or, it means choosing an internal resistance.

➢ Port selection

When injecting a high/low voltage fault, we have to determine to which port of the signal line to inject the fault, the output port or the input port. If D4 is 0, it means choosing the input port. Or, it means choosing the output port.

➢ Operating mode

D3 is used to determine the operating mode of the equipment. If bit D3 is 0, the equipment turns to the work mode. Or, it turns to the test mode.

- Fault type

The equipment can inject 6 types of faults at most, so 3 bits (2^3=8>6) are enough to determine the fault type.

4.2 Command2

The command2 carries the information on injection channel. The equipment can connect 32 signal lines at most, so 5 bits (2^5=32) are enough. "00000" represent the first signal line and "11111" represent the last signal line. In addition, the unused 3 bits (D2, D1, D0) are set to 0.

4.3 Command3

The commad3 carries the information on resistance values. As is shown in Figure 4, each bit corresponds to a relay. If the value of a bit is 1, the corresponding relay is closed. We can adjust the size of resistance connected to circuits by changing the values of the bits. It is remarkable that command3 can absolutely not be 1111-1111.

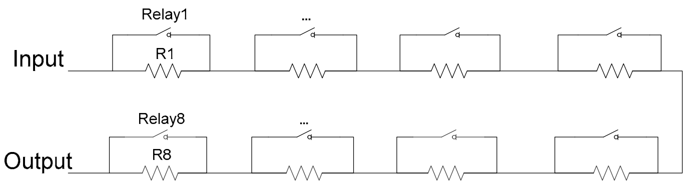

Figure4 : The basic principle of command3

4.4 Command4

The command4 is the termination command. After recognizing the command4, the equipment will revoke the fault which has been injected and restore the equipment to its original status by closing all the relays. The termination command is set as 1111-1111 to avoid being the same as other commands.

5. Verification of BIT detection capability

5.1 Verification process of BIT detection capability

The fault injection equipment can be used to verify the BIT detection capabilities of electronic products, and the main process is shown in Figure 5.

Step1: Connect the fault injection equipment with the electronic product to be injected;

Step2: Self- test of the fault injection equipment;

The equipment should be maintained if the self-test result is faulty.

Step 3: Input the fault injection related information through fault injection software;

The fourth, the fifth and the sixth step are implemented by the fault injection equipment automatically.

Step 4: Select the signal line to be injected;

The fault injection equipment receives commands sent by the PC, and select the signal line to be injected.

Step 5: Judge the time-character of fault to be injected;

Step 6: Fault simulation and injection;

The fault simulation process differs according to the time-character of faults.

For transient fault, the fault simulation board simulates the corresponding type of fault by changing the status of relays at first. After keeping the status of relays for a short time, the equipment revokes the injected fault and keeps this status until the end of the injection process.

For intermittent fault, the fault simulation board simulates the corresponding type of fault and keeps the injection state for a short time. Then the equipment revokes the injected fault and keeps this for another short time. By recycling this process, we can achieve the simulation of intermittent faults.

For permanent fault, the fault simulation board simulates the corresponding type of fault and keeps this status until the end of the injection process.

Step 7： Confirm whether the expected fault has been injected to the equipment effectively;

We can confirm whether the expected fault is injected into the electronic product effectively with other measuring instruments. If not, we should go to step 3.

Step 8：Observe the BIT reactions of the injected electronic product and record the results.

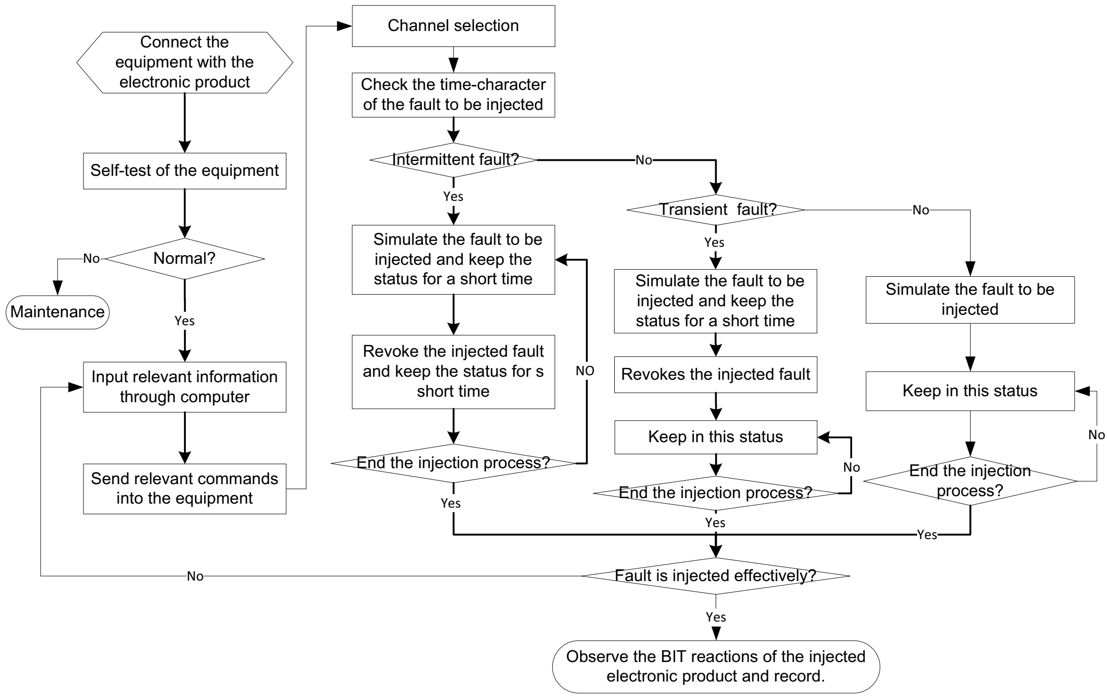

Figure 5: Verification process of BIT detection capability

5.2 Application

Based on the equipment and the process mentioned above, an environmental control system is taken as an example of BIT detection capacity verification (Jun-You Shi, 2011).

Firstly, get all the 113 types of possible faults of the environmental control system through FMEA (Shi et al., 2011). Among all the faults, 62 types of faults can be injected by the automatic line fault injection equipment.

Secondly, select an appropriate line and inject corresponding type of fault for three times: the first time is the instantaneous fault, the second time is the intermittent fault and the last time is the permanent fault. Then, observe the BIT reactions and record the result after confirming the fault has been injected. What is shown in Figure 6 is the voltage waveforms of a signal line after being injected open circuit faults of different time-characters.

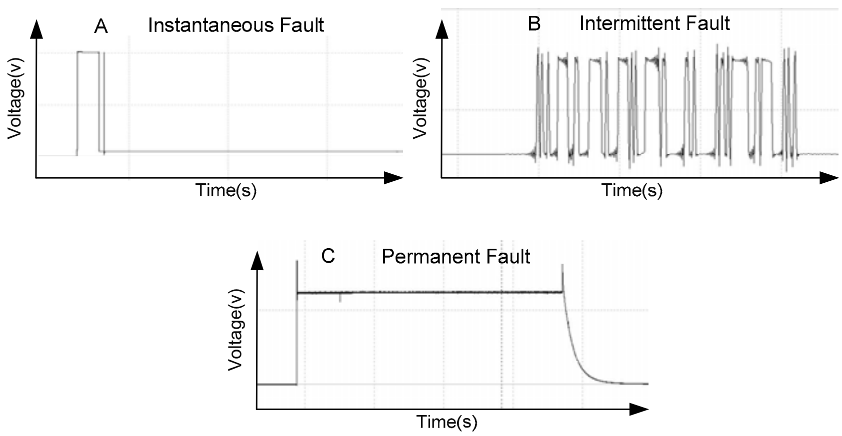

Figure 6: Voltage waveforms of a signal line after being injected open circuit faults of different time-characters

Finally, repeat above steps until all the 62 types of faults have been injected. Statistic the results and compare the BIT detection capacities to faults of different time-characters. As is shown in Table 1:

Table 1:Comparison result

Time character	Alarm times of BIT	Alarm rate of BIT
Instantaneous	7	11.3 %
Intermittent	20	32.2 %
Permanent	57	91.9 %

This fault injection equipment can just inject 6 types of faults, so the BIT detection capacities of the environmental control system shown in Table1 are not accurately enough. However, it is still reasonable to make the following assumption: the BIT detection capacity to permanent faults is the highest, and the BIT detection capacity to instantaneous faults is the lowest.

6. Conclusion

The automatic line fault injection equipment described in this paper has the advantages of high integration, strong universalization because of the adoption the USB interface technology and the FPGA technology. It has been proved that the equipment can verify the BIT detection capabilities of electronic products effectively.

At the same time, deficiencies still exist: the adoption of relays in the fault simulation board and the channel selection board brings out turn-off peak voltages. These peak voltages have negative impacts on fault injections. Therefore, we should take other methods such as signal filtering technology (Boudraa et al., 2007) to eliminate such influences in later studies.

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