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Radiation Hardened Controller Using COTS Technology

Changhwan Choi*, Namho Lee, Youngsoo Choi, Seongsoo Kim and Seungho Jung
Nuclear Robotics Lab., at the Korea Atomic Energy Research Institute,
150 Deokjin-dong, Yuseong, Daejeon 305-353, Korea
* e-mail : madistcch@kaeri.re.kr

1. Introduction

The robots working in a nuclear power plant experiences severe radiation dose while performing given tasks. This high radiation level damages and changes the characteristics of the material that composed of the robot which can be the rubber, glass, semiconductor materials, and so on. The damage on the semiconductor material is more critical because the controllers of the robot are mostly composed of them.

Many researches have been performed to construct a reliable controller targeted for high radiation region using commercial off-the-shelf (COTS) semiconductor devices especially in space application. The cosmic ray particles are 90 percent protons and 7 percent of alpha particles. On the contrary to the space environment, the nuclear power plants have severe gamma ray and neutron. Sharp described the radiation effect of the power semiconductors for nuclear industry [1]. Alexandre and Marceau had developed a radiation hardened robot controller and applied it to a commercial remote controlled robot, Andros [2].

This paper presents a radiation hardened redundant controller (RHRD) for the nuclear robots using COTS technology. The controller has two DSP controllers and one emergency controller. One of the DSP controllers is the main controller that is working in normal operation. The other DSP controller is a redundant cold standby system. This cold standby system is enabled if the main DSP controller is not working. The emergency controller is purely composed of mechanical relays which is not affected by the irradiation.

2. Radiation Hardening Scheme

The semiconductors are most sensitive electronic device in radiation when constructing a robot controller. When the semiconductor is exerted on the radiation, various electrical parameter of the device is changed. The interaction of this ionizing radiation causes electrons and complementary holes and can cause unwanted effects in the latch state or memory cells of semiconductor devices. These unwanted changes are known as soft errors and are a type of single event upset (SEU). Moreover, if the heavy ion passed through the parasitic PNPN structure of a chip, the thyristor like structure stay opened which can be happened between the two power source and substrate, destructively high current can be involved, which is called as single event latchup (SEL).

The MOSFET type transistor is a basic component of modern integrated circuit. The bias voltage applied to it captures the charges generated by the radiation in the oxide layer, which caused the change of the threshold voltage of the MOSFET. This effect causes a change in the values on the register in a microprocessor and RAM, which causes the SEU. Since the microprocessor and RAM are composed of many transistors, there are more possibility for SEL. When SEL is occurred in the ICs, although not all of the ICs are destroyed, but some of the MOSFET can be damaged which causes the SEU or becomes a permanent damage to the controller. In order to prevent this kind of radiation effect, a redundant cold standby system is attached in the main controller. The redundant controller is turned off while normal operation. Therefore, the charges generated by the radiation in the oxide layer transferred to the substrates or easily flow out to the layer. Moreover, since there is no power in the power line, SEL does not occur.

3. Radiation Hardened Redundant Controller

Figure 1 shows the block diagram of the RHRC. The main controller of the RHRC is constructed by using a DSP controller, TMS320F2812 made by Texas Instrument, which is denoted as number 1 in the figure. In addition to the main DSP controller, the RHRC has two kinds of redundancy. One is the second DSP controller denoted as number 2. The other is an emergency controller denoted as number 3. The main DSP controller takes charge of the usual operation in normal condition such as communication with the host computer and management of the robot operation. In this normal condition, the second DSP controller is not working. Even more, the power of the second DSP controller is turned off to reduce the radiation effect. If the main DSP controller is not working unexpectedly, the robot operator can switch off the main DSP controller, power on the second DSP controller, and switching the control privilege to the second controller by switching the controller switcher relay. There are 55 mechanical relays with two relays in one package. These relays are for disconnecting the digital ports of the controller from the external circuits. Since the digital port could be latch up or latch down caused by the radiation effect, it is safe to disconnect mechanically.

The purpose of the second DSP controller is for retracting the robot to the maintenance room. We hope to secure as much time as possible by using the second controller. While the robot is working in the radiation environment, the two DSP controllers experience same irradiation dose. The main DSP controller has more possibility to SEU and SEL than the second DSP controller.

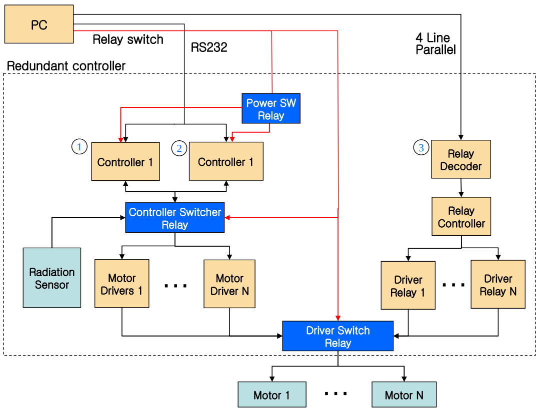


Fig. 1. Configuration of the Radiation Hardened Redundant Controller

4. Experiments

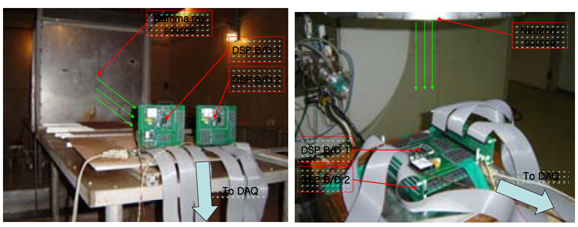
4.1 Experimental setup

Figure 2(a) and (b) shows the experimental setup of the gamma ray and neutron irradiation test. Two DSP controllers are used for the experiment. The 16 bit parallel data is transferred to the DSP, and the DSP bypasses the data to the DAQ. The acquired data is transferred to the PC through the RS232 line and the two DSP also transfers the received data from the DAQ to the PC through the RS232 line. By using this test method, we can see three cases.

1. If both the DAQ and DSP status are observed to the PC, and the data is correct, then the DSPs are working well.

2. If DSP status is not observed but the DAQ data is correct, then the communication port is down.

3. If DSP status is not observed and the DAQ data is not correct, then the DSP is down.



(a) (b)

Fig. 2. Experimental setup for gamma ray and neutron irradiation tests.

Table 1. Gamma ray irradiation test result

Time(h:m:s)	Status
0:00:00	Start the gamma irradiation
0:23:08	Communication error, main DSP down
0:23:10	main DSP off/on
0:23:10	main DSP damaged
0:33:00	second DSP on
0:52:10	second DSP off/on
0:52:10	second DSP damaged

The dose rate of the gamma ray is 50krad/h. Table 1 summarizes the test result. If only one DSP is used, the radiation hardening performance is 23.4 krad. The proposed RHRD endures 34.4 krad by using the redundancy configuration. 47% increase of the performance.

The dose rate of the neutron is 400rad/h. Figure 3 shows the event plot of the test. On the contrary to the gamma ray irradiation test, the neutron irradiation test shows complex trend. The communication error is occurred at the 1:23 second, but the DAQ response is correct, which means that the main DSP is still working. At 19:01 second, the main DSP is down. If we turn off and turn on the DSP again, the DSP is working well, which means that the SEU has been occurred. Until 3:40:00 second, this pheonomenon is continued. We cannot observe the complete failure of the main DSP controller in neutron irradiation test, but we determined that the DSP cont roller can endure the 1.4 krad of the neutron irradiation based on the 3:40:00 second.

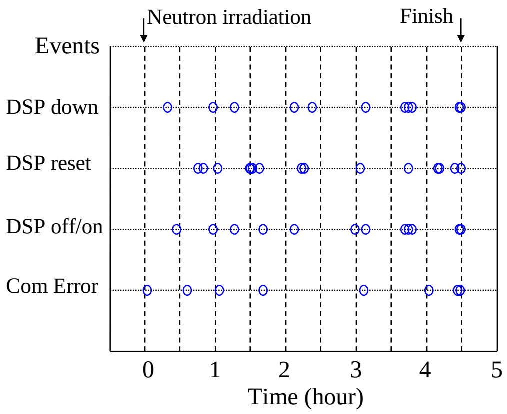


Fig. 3. Neutron irradiation test result.

5. Conclusion

The COTS technology based low cost approach enables the application of the high performance state-of-art semiconductor technology in the nuclear industries. The gamma and neutron irradiation endurance tests show the feasibility of the redundant configuration of the controller to increase the durability on the irradiation.

Acknowledgment

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REFERENCES

[1] R. E. Sharp, “Radiation effects on power semiconductors [nuclear power industry,” IEE Colloquium on Power Semiconductor Devices, pp. 7/1 - 7/6, 1994.

[2] J. M. Alexandre and M. Marceau, “Development of a 10 kGy(Si) rad hard controller for mobile robot using COTS,” IEEE Fifth European Conf. on Radiation and Its Effects on Components and Systems, pp. 394 - 400, 1999