Research on Single Event Effects of Ethernet MAC Controller on Manned Spacecraft

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Abstract: In order to realize higher speed and large flow network communication on the new manned spacecraft independently developed in China, it is necessary to apply Ethernet technology. Considering the cost and application prospect, it is planned to use industrial Ethernet control chip. So it is necessary to verify whether it can meet the special requirements of the space environment. According to the space environment of the manned spacecraft design orbit, and the sensitive characteristics of the Ethernet controller chip itself, it is necessary to focus on verifying its single-particle effect. This paper introduces in detail the single-event effect of the Ethernet controller in China for the first time. The Bi-ion and Kr ions of the HIRFL cyclotron are used to carry out the single-event effect on the KSZ8851-16MLLJ Ethernet MAC controller produced by MICREL. The evaluation test, including the single-particle test design, hardware platform, software functions and test data, finally gave the test conclusion.

1. Introduction
China is designing and manufacturing manned spacecraft that can operate in space for a long time. The network communication function of manned spacecraft is very important, including internal spacecraft communication and communication with the ground. The data bus used in China's manned spacecraft is the 1553B bus, and its communication rate cannot meet the higher data communication speed and data flow of the new manned spacecraft, so more advanced network communication technology is needed. The application of Ethernet technology to manned spacecraft can meet the requirements of network communication, but it must be ensured that the Ethernet controller chip used can meet the special operating conditions of the manned spacecraft. In consideration of cost and application prospects, an industrial-grade Ethernet control chip is planned to be used, and its anti-irradiation characteristics are not clear, so it is necessary to verify the space environment and the sensitive characteristics of the Ethernet controller chip itself. Radiation exists in the space environment, mainly including: single particle effect, total dose effect and displacement damage effect[1]. Among them, the single-particle effect is the most important factor that causes anomalies in the orbit of the spacecraft, so it is necessary to evaluate the single-particle effect of the chip[2].

2. Principle of single particle effect
The single-particle effect is a radiation effect caused by a single high-energy proton or heavy ion incident on an electronic device. This article focuses on single-particle flipping and single-particle locking.

Single particle inversion (SEU) is a kind of charged particle radiation effect that occurs in logic
devices and logic circuits with monostable or bistable states\cite{3}. When a single high-energy charged particle bombards a chip of a large-scale, ultra-large-scale logic microelectronic device, an ionization effect occurs near the PN junction inside the chip along the incident trajectory of the particle, generating a certain number of electrons ~ holes Right (carrier). If the chip is in a power-on state at this time, these carriers due to radiation will drift and redistribute under the action of the electric field inside the chip, thereby changing the normal carrier distribution and movement state inside the chip. When the change is large enough, it will cause the change of the electrical performance state of the device, causing logical errors in the logic device or circuit. Its harms may cause errors in various monitoring data of the spacecraft, and in other cases, it will cause the spacecraft to execute incorrect instructions, causing the spacecraft to occur. Abnormal orbits and malfunctions have even put the spacecraft in a catastrophic situation\cite{4}.

Latchup it occurs in bulk silicon (Bulk) CMOS process devices one kind of harmful great space radiation effects. It may cause harm to the spacecraft in three areas: First, SEL devices and instruments that may be generated occur SEL high current (several hundred or even a few mA A) burned, the second is the star of the secondary power supply device may be used this sudden surge damaged by the load current, the third is the device when the power supply by the secondary impact causes the output voltage changes SEL use, working instrument using the same satellite on the other second power supply may be affected\cite{5}.

3. Single particle effect description

LET (linear energy transmission) values and single-particle effect sections (such as flip sections, locked sections, burned sections.) are usually used to describe the single-particle effect characteristics of electronic devices\cite{6}.

The LET value describes the energy deposition characteristics of incident particles in the device. The LET value of high-energy heavy ions in the material is related to the ion energy and the type of material. The physical meaning of the LET value is: the energy deposited per unit distance when high-energy ions are transported in the material, that is, \( \text{LET} = \frac{dE}{dx} \), the amount The outline is MeV.cm\(^2\) / mg or MeV.cm\(^2\) / g. It is generally believed that the ability of particles with the same LET value to produce the single-particle effect is the same, so LET becomes a normalized measure of the ability of heavy ions of different types and energies to produce the single-particle effect\cite{7,8}.

The single-particle effect cross section describes the single-particle effect characteristics of the device under the bombardment of high-energy particles with a certain LET value\cite{9}. Taking a single particle inversion cross section as an example, \text{SEU} is the ratio of the number of device inversions \text{NSEU} to the total number of incident particles \text{NP}, the dimension is cm\(^2\), that is:

\[
\text{SEU} = \frac{\text{NSEU}}{\text{NP}}.
\]

Therefore, the flip cross section refers to the probability of a single particle flip event occurring on a unit area of a single particle incident on the device. The size of the cross section depends on the LET (or proton energy) of the incident heavy ions and the single-particle sensitivity of the device itself\cite{10}.

For manned spacecraft, high-energy protons in the radiation zone of the Earth, high-energy protons and heavy ions in the solar cosmic rays and galactic cosmic rays are the main sources of radiation that can trigger the single-particle effect. High-energy heavy ions induce single-particle effects through direct ionization, while high-energy protons have small LET values. The single-particle effects are mainly caused by heavy ions generated after a nuclear reaction in a device\cite{11}.

4. Internal structure of the test object

KSZ8851-16MLLJ is a single-ended Ethernet MAC control device, with 8-bit or 16-bit Gigabit Ethernet transceiver. The internal structure of the device is shown in Figure 1. Contains a Fast Ethernet MAC controller, an 8 / 16-bit general-purpose host processor interface, and integrates a unique dynamic memory pointer, with a 4-byte buffer boundary, and a fully usable 18KB space for host buffering Both the transmit (6KB allocated) and receive (12KB allocated) directions of the device interface can be used. The KSZ8851-16MLLJ is designed using a low power CMOS process and uses a single 3.3V power supply with 1.8V, 2.5V, 3.3V VDD I / O options. Includes a rich feature set,
provides management information database (MIB) counters, and a CPU control / data interface with a single bus timing[12].

![Device functional block diagram](image)

**Fig 1 Device functional block diagram**

5 overall scheme of the test system

First, based on the single-particle lock sensitivity of the device, it was determined that the Bi ion and Kr ion of the HIRFL cyclotron were used to perform a single-particle effect test on the KSZ8851-16MLLJ Ethernet MAC controller manufactured by MICREL. The selected particle type, energy, and LET value and range in silicon are shown in Table 1.

| Source location | Accelerator | Ionic species | Energy (MeV) | LET(MeV/mg/cm²) | Range (μm) |
|----------------|-------------|---------------|--------------|-----------------|------------|
| Lanzhou Institute of modern physics | HIRFL whirl | $^{84}$Kr | 480 | 37.62 | 85 |
| | | $^{209}$Bi | 1731 | 99.8 | 93.5 |

The purpose of the test is to grasp the sensitivity characteristics of KSZ8851-16 Ethernet MAC controller single particle lock and single particle function interruption, to obtain the LET threshold data of the device single particle lock and single particle function interruption, and to give the conclusions.

In order to improve the accuracy of the test, three KSZ8851-16MLL were randomly selected from the same batch of devices for testing. Due to the low energy of heavy particles in the single-particle effect test, it is not possible to directly penetrate the chip's shell. Therefore, it is necessary to uncap the device before the test. The overall morphology of the device after capping is shown in Figure 2 and the internal morphology is shown in Figure 3.

![Overall morphology of the device after opening the cap](image)

**Fig 2 Overall morphology of the device after opening the cap**
During the test, the three KSZ8851-16MLL on the test board are always powered on. The status of the KSZ8851-16MLL is read in real time by connecting to the upper computer. The radiation source is used to sequentially illuminate the KSZ8851-16MLLJ after the cap is opened. When KSZ8851-16MLLJ is used, when there is a significant change in performance or function, when the criterion for the single-particle effect is reached, corresponding measures are taken, and the amount of radiation at that time is recorded as the threshold value of the KSZ8851-16MLL anti-single-particle effect\textsuperscript{[12]}.

In the test, a particle accelerator was used to illuminate the device under test, and at the same time, the power supply current, the internal memory unit flip and the chip function were remotely monitored. The test system irradiation board is composed of 3 test samples (1 # ~ 3 # board), 1 standard sample (4 # board), 4 TMS320F2812, remote PC monitoring, and CAN bus and Ethernet bus. As shown in Figure 4, the test site is shown in Figure 5.

The host computer software sends commands to the corresponding DSP through the CAN bus. The 1 #, 2 #, and 3 # DSPs respectively control the corresponding Ethernet control chips, and by calling the corresponding chips, test their control and data transceiver function modules. The software (lower computer software) in the DSP completes the functional test of the chip and the sending and receiving of data. The KSZ8851-16MLLJ chip sends the test data to the host computer for comparison test by using the Ethernet bus through the isolation transformer and RJ45 interface\textsuperscript{[13]}.

The irradiation test board is equipped with three chips to be tested: the functions of the bus interface unit, phase-locked loop, registers, EEPROM, voltage, and data transmission and reception.
within the chip are tested. The lower computer software analyzes and counts the internal interrupts, registers and other functions of the KSZ8851-16MLLJ chip according to the instructions sent by the upper computer, and sends them back to the upper computer for monitoring. The DSP chip has a data acquisition function to collect and monitor the power supply voltage and current of the chip under test\[14\].

6. test system software functions

6.1 CAN bus communication function

The 4 # board uses the CAN bus notification to test the 1 # board. The data collected by 2812 on the 1 # board (3.3V, 1.8V, 3.3VI, 25MHz) is transmitted to the 4 # board through the CAN bus, and then through the Ethernet port. Send to the host computer. Through the configuration of the mailbox, the 4 # machine is controlled to send data to 1 #, 2 #, and 3 #, and the sent data is detected by the upper computer. By configuring the mailbox, the 1 #, 2 #, and 3 # receive the instructions from the 4 # machine, and then send data to the 4 # machine and detect the data through ZLG CAN test. 4 # machine notifies 1 #, 2 #, and 3 # to receive the data, and then sends data to 1 #, 2 #, and 3 # respectively and completes the data comparison by 1 #, 2 #, and 3 # and informs the 4 # machine of the result. 4 # sends a send data command to 1 #, 2 #, and 3 #. The received data of 1 #, 2 #, and 3 # are compared with standard data, and the control of receiving and sending data is performed cyclically. 4 # Upload the comparison result of the control and reception data with the host computer.

6.2 PC software function

Realize the UDP communication between the host computer and 4 #, the host computer controls the 4 # to send commands and send and receive data, the host computer displays the test instructions in real time, the host computer sends and receives data every one second, and displays it in real time. Particle lock) to realize automatic power-off of the system, store the received data into a spreadsheet, and play back and display the stored data. The upper computer interface is shown in Figure 6.

6.3 Lower computer software functions

TMS320F2812 control of KSZ8851-16MLLJ, UDP communication (broadcast) of KSZ8851-16MLLJ,CAN communication between boards, write test samples to 1 #, 2 #, 3 #, 4 #, UDP communication and CAN communication of 4 # and 1 #, 2 #, 3 #, customize the transmission data format, collect the time and The data is transmitted to the upper computer through CAN and UDP communication. The test board is compared with the sample when sending and receiving data. If there is an abnormality, the upper computer is notified to automatically power off the system.

6.4 Register function monitoring

The registers that can be monitored within the KSZ8851-16MLLJ include readable and writable registers and readable registers. Since most of the readable and writable registers are used in the
Ethernet communication process, the functions of these registers can be monitored through the Ethernet communication status. Therefore, the unused readable and writable registers and readable registers need to be monitored separately. When an error occurs in the monitored register, the number of registers with errors is recorded.

6.5 receive fifo and send fifo test
Receiving and sending are transmitted in 1K bytes, and the content of each byte is OXAA or OX55. By detecting whether the received and transmitted bytes are consistent, it is detected whether a single particle flip occurs. Count the number of bytes that occurred, then upload to the host computer, and save and record it[15].

7. Test items and main data
The device was tested for single particle lock on the HIRFL cyclotron. The results of the test data are shown in Table 2.

| Model specification | number | Detection mode | particle | LET MeV.cm²/mg | Particle range | Total particles / cm² | SEL times |
|---------------------|--------|----------------|----------|----------------|-----------------|----------------------|-----------|
| KSZ8851-16MLLJ      | 001#   | signal output  | Bi       | 99.8           | 53.7μm          | 3.74 x 10⁴           | 3         |
|                     | 002#   | signal output  | Kr       | 37.62          | 58.5μm          | 1 x 10⁷              | 0         |
|                     | 003#   | signal output  | Kr       | 37.62          | 58.5μm          | 1 x 10⁷              | 0         |

8. summary
KSZ8851-16MLLJ Ethernet MAC controller with Bi ion irradiation with LET of 99.8 MeV.cm² / mg was used. In the signal output mode, a total of 3.74 x 10⁴ particles / cm² fluence was detected, and a total occurrence of devices was detected. Three single-particle locking effects indicate that the device's LET threshold for single-particle locking is lower than 99.8 MeV.cm² / mg.

Using a Kr ion irradiation KSZ8851-16 Ethernet MAC controller with a LET of 37.62 MeV.cm² / mg, in the signal output mode, during the irradiation to a 1.00 x 10⁷ particle / cm² fluence, no device list was detected. The particle locking effect indicates that the LET threshold of the device against single particle locking is greater than 37.62 MeV.cm² / mg.

Based on the results of the test data, the conclusions are as follows: The LET threshold of the device against single-particle locking is less than 99.8 MeV.cm² / mg, and greater than 37.62 MeV.cm² / mg. According to the relevant construction specifications for comprehensive analysis, we can draw conclusions: the KSZ8851-16 Ethernet MAC controller meets the requirements of anti-single particle locking on components on spacecraft. So it can be applied to China's new manned spacecraft.

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