Radiation Testing of High-Speed LSIs for the Next Space VLBI Satellite

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ABSTRACT

We have performed two types of radiation testing (a total ionization dose experiment and a single event effect experiment) toward high-speed LSI chips (a decision circuit and a demultiplexer) for the wideband observation by space VLBI. We could not see any change of autocorrelation spectra and current due to the ionizing radiation. On the other hand, we had a few tens of single events for each LSI due to the irradiation of heavy ions. We estimated the occurrence rate of single events in space as about one time per hour from our experiment, and we could not see the single event latch-up in any LSIs. We therefore consider that these LSIs have sufficient tolerance for the space environment.

INTRODUCTION

The first space VLBI satellite, HALCA, was launched on 12 February 1997 and observations succeeded between HALCA and ground radio telescopes at 1.6, 5, and 22 GHz [1]. HALCA is the main element of the space VLBI mission, the VLBI Space Observatory Programme (VSOP).

In order to accomplish higher angular resolution and better sensitivity than VSOP, we are planning the next space VLBI mission (hereafter VSOP-2) and are considering several development items. One of the key technologies for the wideband observation is a high-speed data sampling system. The downlink rate is 128 megabit per second (Mbps) for HALCA, we aim data sampling rate of more than 1 Gbps by VSOP-2 satellite. Although data sampling and recording at more than 1 Gbps has already been accomplished on ground VLBI systems, such a sampling rate has not been realized yet in an onboard system. In order to check the tolerance of high speed LSIs in space, we performed two types of radiation testing. One is a 'total ionization dose (TID) experiment' (to check variation of the characteristics in an LSI due to the total radiated dose) and the other is a 'single event effect (SEE) experiment' (to check latch-up and/or bit error features due to the interaction of charged particles).

Here we report the outline and the results of these two experiments and discuss the expected performance of the LSIs in the space environment.

OUTLINE OF THE EXPERIMENTS

The experiments were carried out at Takasaki Institute, Japan Atomic Energy Research Institute (JAERI) on 12 April 2001 (TID) and 7 August 2001 (SEE). The tested devices are i) a decision LSI (1-bit quantization circuit; hereafter DEC), and ii) a demultiplexer (converts one data stream into 16-bit parallel data; hereafter DEMUX), both of which are GaAs devices and have the capability of a maximum data processing rate of 10 Gbps (see Fig.1).

If we assume the similar orbit and the lifetime as HALCA (apogee height of 21,000 km, perigee height of 1,000 km, and nominally three years), 1 kGy of total ionizing radiation and 80 MeV/(mg/cm ^{2}) of the incidence level of the linear energy transfer (LET) are needed.

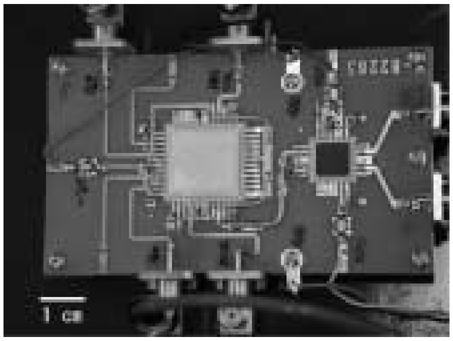

Figure 1: Tested devices; a demultiplexer (left) and a decision LSI (right).

TOTAL IONIZATION DOSE EXPERIMENT

In the TID experiment, five DECs and DEMUXs were prepared and a dose rate of 1 kGy – 10 kGy irradiated each device using a cobalt-60 gamma-ray source. We checked the autocorrelation spectra using random noise input before and after TID experiment (see Fig.2), and monitored the current of all devices after the experiment. Fig.3 and 4 show the monitored current of the DECs from the end of the radiation testing to 1,000 hours later, and the autocorrelation spectra before and after the experiment, respectively. We could not see any change of autocorrelation spectra and current due to the irradiation.

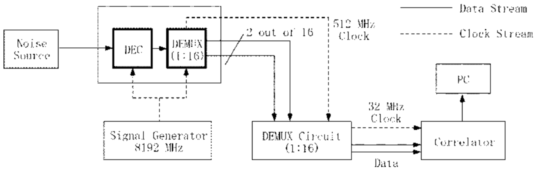

Figure 2: Schematic diagram of the autocorrelation measurement system for the TID experiment.

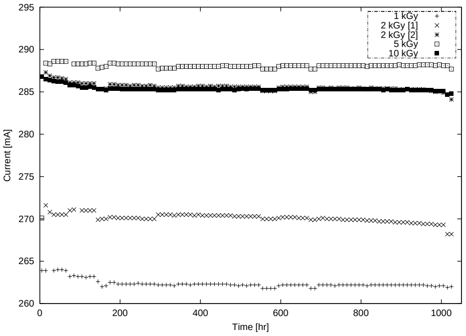

Figure 3: The current as a function of time for the decision LSIs. Current monitoring was carried out until 1,000 hours after the irradiation.

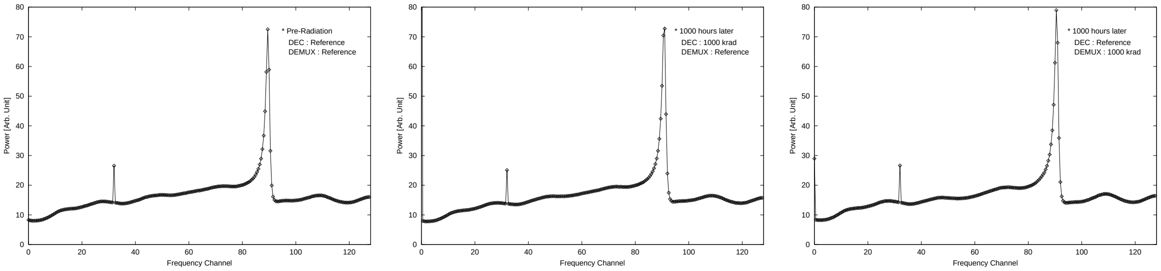

Figure 4: Autocorrelation power spectra. The horizontal axis is the intermediate frequency channel (one channel corresponds to 4 MHz bandwidth) and the vertical axis is the power (arbitrary unit). (Left) before the experiment, (center) 1,000 hours later from the experiment with DEC (10 kGy irradiation) and DEMUX (non-irradiation), (right) 1,000 hours later from the experiment with DEC (non-irradiation) and DEMUX (10 kGy irradiation).

SINGLE EVENT EFFECT EXPERIMENT

In the SEE experiment, three DECs and DEMUXs were prepared and three heavy ions, Kr, Ar, and Ne were used to irradiate the devices. Although electrons and protons are the main particles which cause a single event in the space environment, these heavy ions were used in place of electrons and protons because the effective energy transfer to the device is the same. Cross correlation between the data from radiated and non-radiated devices were taken in the experiment (see Fig.5), and the source current of the devices was also monitored under irradiation.

We could see single event upsets (SEU) as $n\pi$ phase jumps against the initial phase. In this experiments, a 180-deg phase jump corresponds to a 1 nsec delay between the data from radiated and non-radiated devices. This phase jump can be accounted for as a clock reset of DEMUX due to the interaction of heavy ions because one data lag between outputs from radiated and non-radiated devices corresponds to a one nanosecond delay. On the other hand, we could also find similar phase jump when heavy ions were radiated to the DECs. The clock output from DECs is not used as the drive clock of DEMUXs, then we guess that the phenomena has some effect on the register circuit in the DECs.

We had 20 – 50 single events for each LSI and heavy ion. The irradiation rate in the experiment, however, is much larger than the environment in space and we estimate the occurrence rate of SEUs in space, by CREME96 program (http://crsp3.nrl.navy.mil/creme96/), as about one time per hour from

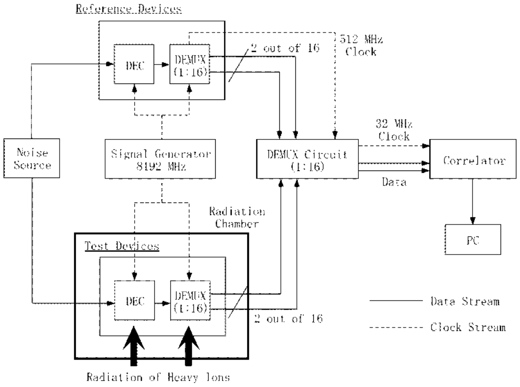

Figure 5: Schematic diagram of the SEE experiment.

our experiment. This is negligible in case of normal imaging observations. Moreover, we could not see the single event latch-up in any LSIs. (see Fig.7). We therefore consider that these LSIs have sufficient tolerance for the space environment.

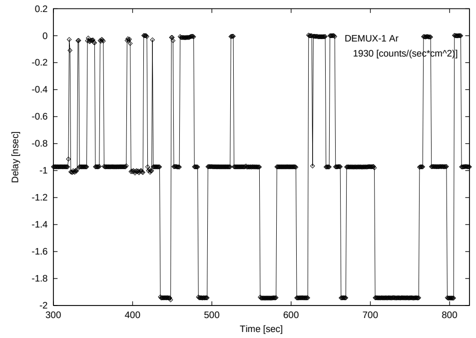

Figure 6: Measured delays from the cross correlated phase. The horizontal axis is the time from beginning to the end of the irradiation and the vertical axis is the delay between the data from radiated and non-radiated devices.

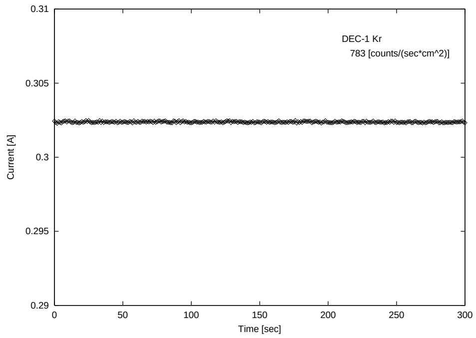

Figure 7: The current as a function of time for the decision LSI in Kr irradiation experiment.

REFERENCE

[1] H.Hirabayashi, et al., “Overview and Initial Results of the Very Long Baseline Interferometry Space Observatory Programme,” *Science*, vol.281, pp.1825-1829, 1998.