JUICE/GALA-J (5): Radiation analysis for Ganymede Laser Altimeter (GALA) for the JUICE mission

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The radiation environment around the Jupiter consists of electrons and protons that are trapped by the Jupiter’s magnetosphere, solar energetic particles and galactic cosmic-rays. The trapped electrons are the most harmful to devices on the JUICE because the trapped electron flux is the most intense and the its penetrability is relatively higher than the other charged particles. The solar energetic particles are of secondary importance in spite of the lower flux because its energy spectrum is hard and the high energy protons easily penetrate a shield.
The most sensitive device to radiation on the GALA is the avalanche photo diode (APD) to detect the laser pulses returned from the Ganymede’s surface. The maximum tolerance, total ionizing dose (TID), is relatively lower than the other devices and is 30 krad. Thus, an adequate shielding is required to reduce the degradation of the performance of the APD. In order to estimate the radiation dose at the APD, a simulation application, GALA-sim and GALA-analy, based on Geant4 [1] and ROOT [2] was developed by GALA Japan to estimate the radiation dose during Jupiter cruising. The application can import for a radiation analysis a three dimensional CAD model which is produced as a result of our structural and strength design of the GALA instrument. It also can estimate the influence of secondary neutron production by nuclear reactions in JUICE in addition to the primary trapped electrons and the solar energetic particles.
The preliminary three dimensional model of the GALA Transceiver Unit (TRU), GAL-TRU-i1.4-Shielding, was developed to analyze the radiation dose during the JUICE mission. The average thickness of mass around the APD in this model is 11.4 g/cm^2 which corresponds to aluminum which 42 mm thickness. The TRU was irradiated with trapped electrons and solar energetic particles by the GALA-sim based on Geant4 version 9.6.p03 and 10.01.p01 and TIDs at the APD due to trapped electrons and solar energetic particles were estimated. They are 21.2 and 0.72 krad (Figure of safety, FoS=2), respectively, if calculated by Geant4.10.01. The sum of TIDs fell below the maximum tolerance of the APD (30 krad). The radiation dose due to the trapped electrons is 30 times higher than that of solar energetic particles as expected. It is found that the trapped electrons with an energy of 10-40 MeV mainly contributes the TID. No dependency on the versions of Geant4 was observed and both results are consistent each other within 3% difference. The result was also confirmed by the calculation by FASTRAD [3].
The total non-ionizing dose (TNID) which is the energy deposition on a material via non-ionizing processes such as Coulomb scattering, nuclear elastic scattering and nuclear reactions, and results in displacement damage is also estimated based on the theory of non-ionization energy loss by [4] with the help of GRAS [5]. The TNID due to the primary trapped electrons, the primary solar protons and the secondary neutron at the APD is 7.52×10^7MeV/g (FoS=2) which is equivalent to the 50 MeV proton flux of 1.75×10^{10} cm^{-2}. The contributions of each particles to TNID were 71%, 24% and 5%, respectively.

In summary, we have developed a simulation code to estimate the radiation damage of the devices in GALA instrument. We found the reasonable solution for the radiation shielding of the APD. The results of calculation are used for the radiation test of the APD at a beam irradiation facility and the improvement of the design of TRU.

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