Available online at www.pelagiaresearchlibrary.com

Pelagia Research Library

Advances in Applied Science Research, 2012, 3 (1):446-451

ISSN: 0976-8610
CODEN (USA): AASRFC

Shielding protection of electronic circuits against radiation effects of space high energy particles

Omid Zeynali[1], Daryoush Masti[*1] and Saeed Gandomkar[2]

[1]Islamic Azad University, Bushehr Branch, Iran
[2]Islamic Azad University, Borazjan Branch, Iran

ABSTRACT

Space radiation environment in LEO circuits including high-energy protons and electrons and ions and secondary particles, effects on electronic devices in a spacecraft. The use of shield to reduce radiation and using software's to analyze the shield thickness and analysis of radiation-tolerant circuits is essential. In this study, by initial analysis of shield amount needed for satellites in LEO by Fluka, Geant4 software's and MCNP code, it was found out that reducing the dose on a piece of less than 10 Krad to reduce the flux of protons (DDD) , for Orbits below 1000km for almost no additional shielding is required. Shield thickness is usually expressed as aluminum thickness equivalent and only considering the effect of satellites shield (Al 1 ~ 2 gr / cm ²) is sufficient to reduce the dose (self shielding effect). High density shield materials (such as tungsten and tantalum) and low density materials (such as polyethylene) can be considered as an ideal shield. The simulations and calculations in the spherical case, the initial dose regardless of the extra protection was achieved with 75 Krad tried to use a different thickness of the shield, the dose reduced to 7.5 Krad.

Keywords: electron, proton, radiation environment, shield, simulation.

INTRODUCTION

Radiation environment various circuits, such as low earth orbit, the geostationary orbits and the nuclear environment (nuclear power plant), mainly consists of solar wind (including electrons and protons), cosmic protons and ions as primary space environment, radiation. Secondary space environment radiation includes electrons, neutrons and radiations from the brake on the interaction of primary radiation satellite structure materials [1] and also the protons and electrons trapped in the Van Allen belts. All above radiation environments have influenced spacecraft electronic devices like single event effect, displacement damage dose and total ionization dose [2]. They are also effective On the TID and DDD, but have little effects on the SEE [3]. Radiation environments also have similar effects on nuclear power equipment.

2. Theory and Background

Based on previous studies, design of spacecraft shield depends on many factors [4]: 1. Radiation resistance of electronic device used in spacecraft, which is about 2-20 Krad for some parts. 2. The ratio of minimum radiation in which the device cannot function properly to the amount of radiation in a desired location (radiation design margin). 3. The self-shield analysis of electronic circuits. This analysis is performed by Fluka, Geant and MCNP software's [12-14] and then based on these three factors and the effect on the target device, additional shield will be designed if necessary [2,7]. In addition to weakening capability, the weight and volume limitations of radiation shield substance for materials used in spacecraft, we must consider physical and mechanical properties should be concerned.

2-1. Shield gender and type

Depending on the satellite and the conditions of the mission, one of the spot or local shield is used. These two shield types are different because of the weight, volume limitation and also the combination of those parts of spacecraft electronics devices that needed to be shielded [8].For example, the local shield is preferable when a collection of adjacent devices that are sensitive to radiation, should be shielded. When a number of pieces on an electronic board needs shielding in a nuclear environment such as nuclear power plant, it is performed through a shield layer on the entire board. But due to weight constraints for a sensitive device in a satellite, spot shield is ideal. However, the most important factor to design and construct a shield is weight and volume limitation. Required protection of sensitive components used in space electronic boards, depends on environmental radiation dose. Radiation dose is a function of height and fly angle of the spacecraft and also acceptable dose of sensitive parts which depends on the device type. Shield thickness is usually expressed as aluminum thickness equivalent.

When positive ions collide high density materials, they split and produce many secondary particles, consequently to stop the secondary particles more thickness of the material of shield is required [11]. As the light materials weaken the protons better, using these materials reduces the danger of producing secondary particles. But because of their low density, more amount of this material is required. And contrary to heavy materials, they can't weaken the electrons and photons well. Using thick shields have some problems like producing secondary dangerous radiations as neutrons and gamma rays because of collision of these radiations with materials' crust. Choosing useful material as a flake can reduce it too much. Atomic constructions with fewer atoms produce less secondary radiation (especially neutrons) [11].Therefore, to achieve the ideal shield, multi layered shield consisting of layers with high and low densities is suitable. Depending on the radiation environment, the optimal thickness of each light and heavy layer, their material and arrangement can be declared. Arrangement of the layers also influences doses received by an electronic device which is sensitive to radiation. High density shield materials (such as Tungsten and Tantalum) and low density materials (such as polyethylene) can be considered as an ideal shield [1, 4]. Also, some materials like Boron (B^{10}), liquid hydrogen, lead, enriched plastics with oxygen are named as shield. Stopping power is known as a parameter to calculate the shield layer and reducing destructive effects on semiconductors, devices and electronic equipments. The stopping power is a useful concept. It means linear reduction of the energy and is defined as follow [7]:

$$S = -\frac{dE}{dx} \quad (1)$$

The value S for charged particles like protons calculates as:

$$-\frac{dE}{dx} = \frac{4nz^4e^4}{m_0v^2}\mathrm{NB} \quad (2)$$

where

$$\mathrm{B} = \mathrm{Z}\,[\ln\frac{2m_0v^2}{I} - \ln(1-\frac{v^2}{c^2}) - \frac{v^2}{c^2}] \quad (3)$$

e and *v* are the charge and the velocity of a descended particle, *Z* the atomic density, *N* the environment atomic number and m_0 the electron inertia mass. Parameter *I*, the potential of ionization and excitation of environment atoms, is generally measured by testing. Generally, to determine the shield thickness, calculations are based on the total dose and the weakest segment of the satellite be considered as initial point with radiation resistance of 2 Krad. To simulate by MCNP and Geant4 soft ware's [6,10] we choose reliability as 3 (i.e. the radiation resistance of 6 Krad), thus aluminum shield thickness will equal to 4.5 mm. Figure 1 shows the stopping power of protons in aluminum [2]. As shown in this figure, protons with energies of 10 Mev/mm in aluminum shield, loose about 9 Mev energy. More than 85 percent of the protons in the space (considered environment), are in the energy range of 1 - 10Mev, so an aluminum shield with a little more than 1 mm thickness, can stop these protons within itself.

3. Shielding design

Shielding design is performed based on amount of allowed dose in satellite electric subsystems expressed in their catalogs. We used MCNP soft ware's and Geant4 [6, 10] simulation in calculation of radiation shielding. All doses of ionizing particles, including electrons, trapped protons, solar protons and brake radiation ray were considered in this calculation. Aluminum was chosen as a shielding material, due to the weight properties and it's shielding against radiation it is the most usual material in satellite structure. So, using software, different transmission doses in terms of aluminum shielding thickness was calculated and simulated. Figure 2 show the various ionizing doses vs the different thickness of aluminum [2].

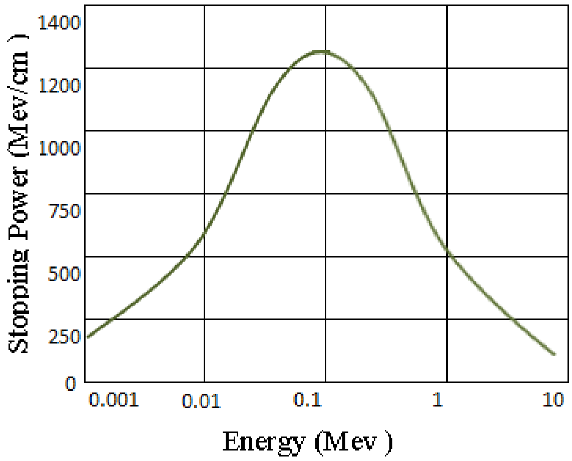

Figure 1.Stopping power of protons in aluminum

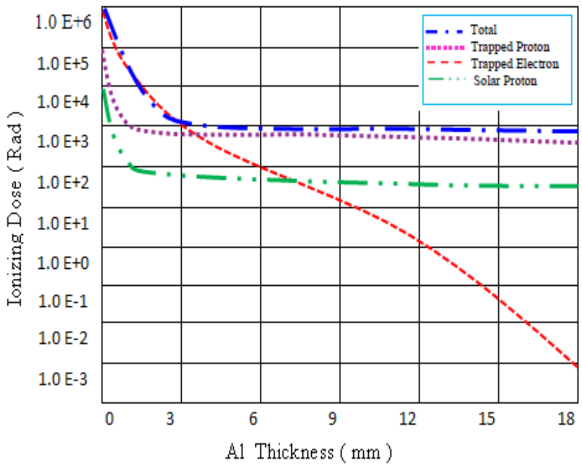

Figure 2. Doses of ionizing depending on the radiation shield thickness

As this figure shows, initial dose of trapped electrons is more than other doses, but these electrons are rapidly absorbed in the shield layer. The amount of transmission dose for the highest dose of proton particles (i.e. the worst case), through different layers is simulated and presented in Figure 3.

In investigating the degree of the effect of orbital parameters on spectrum of charged particles of space which are affective on electronic devices, height and declination angle are of dominant importance. Using Fluka software, diagrams of TID and DDD per 1600 Km height and declination angle 90^0 for aluminum shield in two different surface densities obtained as shown in Figure 4 [1]. According to this Figure, in the height of 1600 Km, we need a very stronger shield. So we will design a shield for this case.

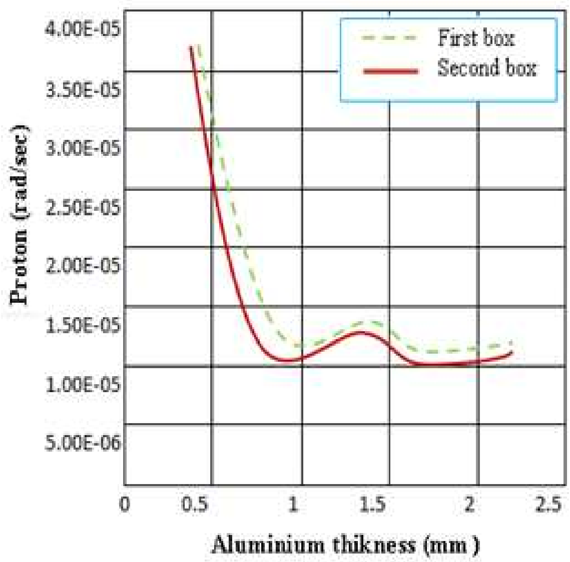

Figure 3. Aluminum shell thickness according to dose per second

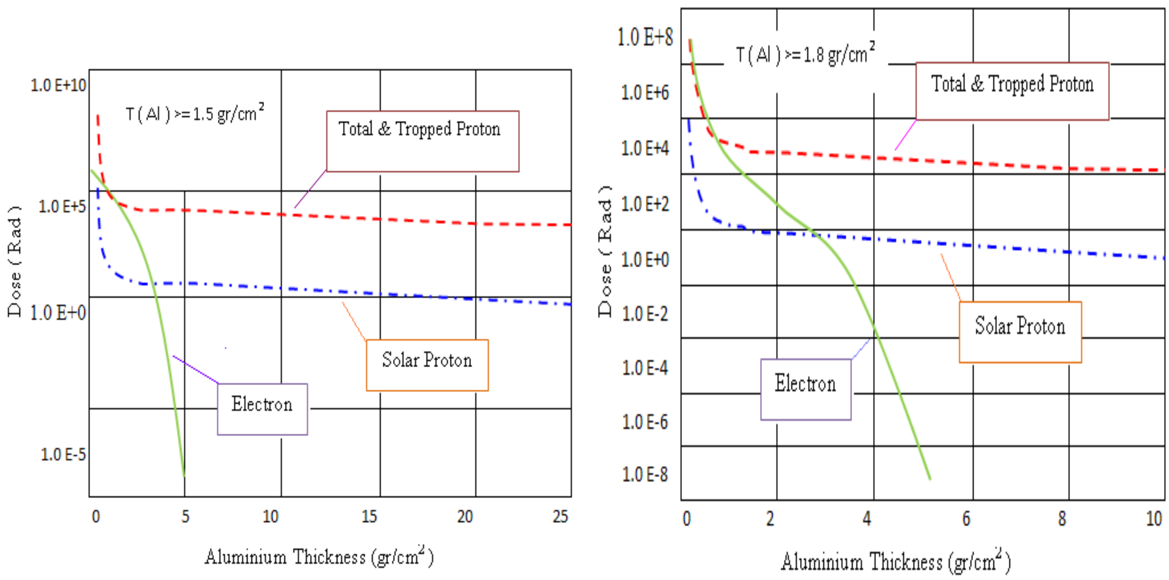

Figure 4. DDD and TID charts for altitude, 1600 Km

3-1. Shield design for the height of 1600 Km

Some information such as altitude, declination angle, the duration of the mission and objective electronic components sensitivity are required for designing satellite shield. As previously said, the flying height of 1600 Km, 90^0 declination angle and also a 5 years mission were considered as conditions for designing the shield. Supposing the objective electronic device is a defect surface (RDM) with a radiation resistance about 15 Krad [2]. The Fluka and MCNP software [5,6] are capable to design the two spherical and flat surface geometry. The results for the four pure materials: aluminum, polyethylene, tungsten and tantalum and four different combinations of these materials are obtained [9]. Based on the results of simulations and calculations in the spherical case, the initial dose without regarding the additional shield layer was achieved 75 Krad. Using different shields with different thicknesses, the dose reduced to 7.5 Krad. In the case of a 15 Krad flat initial dose, it reduced to 1.5 Krad dosage level.

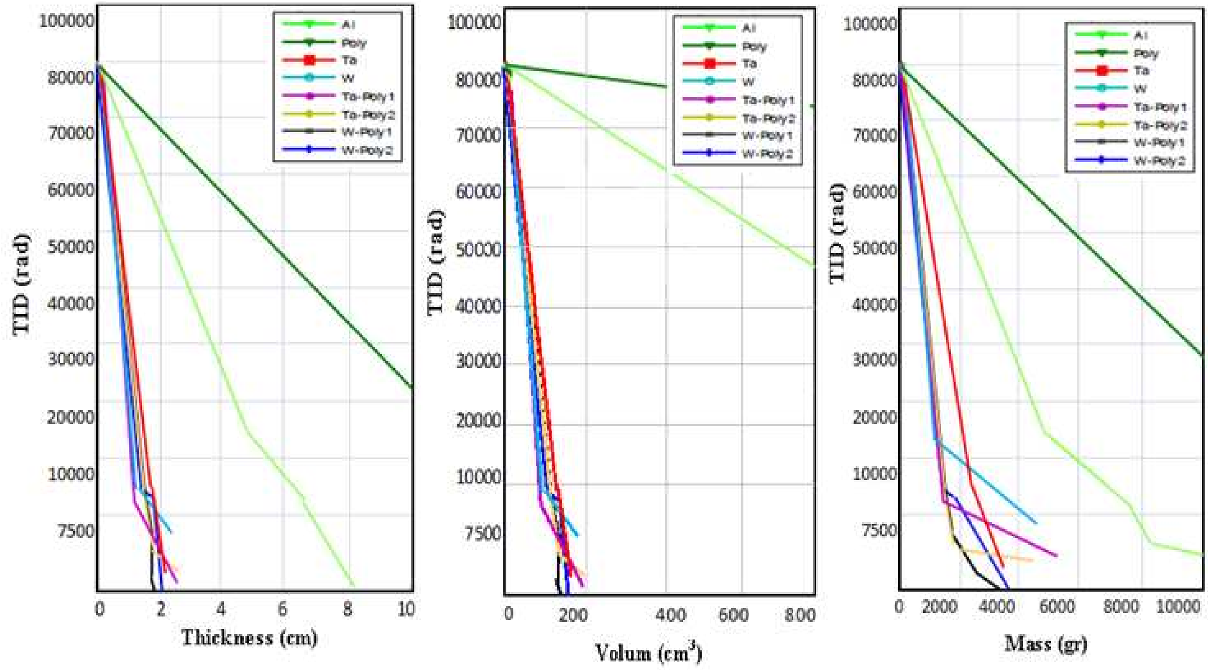

Figure 5. TID charts in terms of thickness, volume and mass of formation material shielding break the spherical shielding

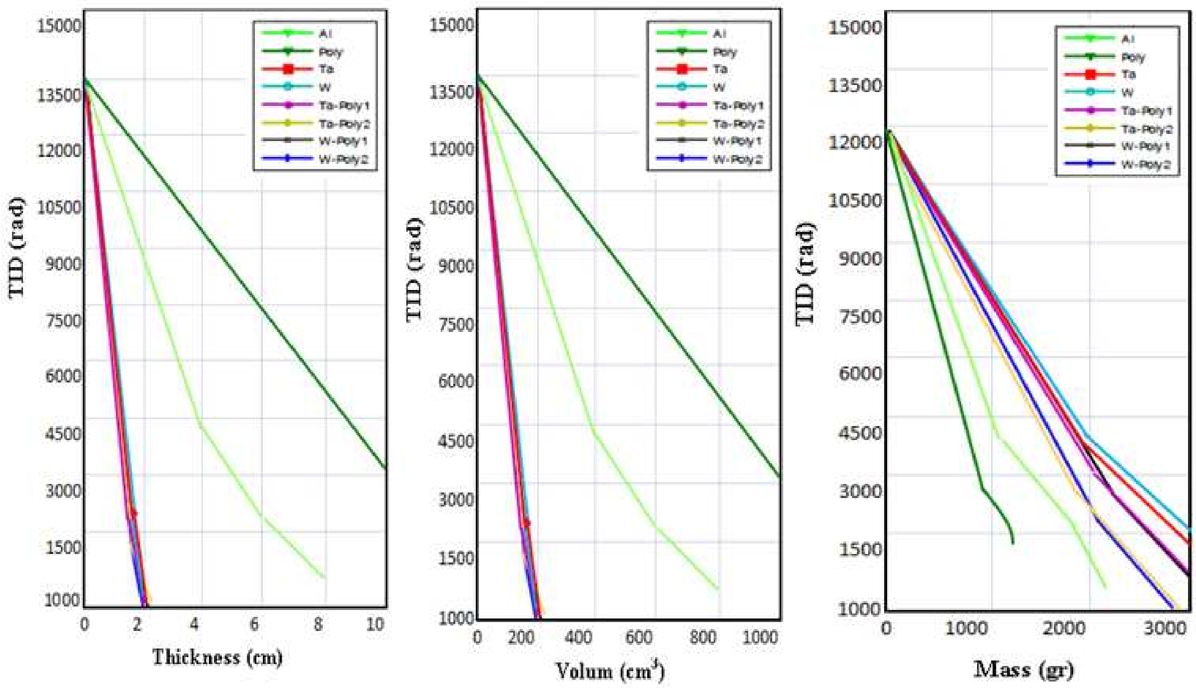

Figure 6. TID charts in terms of thickness, volume and mass of formation material shielding break the flat shielding

In designing shield because of importance of two factors, weight and volume, diagram of dose by shield thickness, volume and mass for both cases: spherical as well as flat shielding, are calculated and shown in Figures 5 and 6. In the spherical case, as shown in Figure 5, the aluminum shielding with a thickness of about 7 cm, with an increase in shield thickness, the volume and as a result mass increase more intensively, therefore light materials are used for shielding in this case [11]. This figure also shows that in designing a spherical shield using the Geant4 and Fluka software, Ta-Poly2 combination shows better performance in comparison with other compounds or pure substances due to thickness, volume and weight. Then the composition W-Poly2, Ta-Poly, W-Poly1, Ta-W and Al-Poly and Ta and W are the Al and Polyethylene [3] respectively. Figure 6 shows that in flat case when the thickness of aluminum shield is about 6 cm, volume and mass increase less intensively with an increase in thickness. So in flat shielding, for light materials, volume limit does exist and in case of heavy materials, weight limit. In this figure it is evident that a volume compound like W-Poly2 shows better performance than the other compounds and pure substances. Then, respectively the combinations of Ta-Poly2, W, W-Poly1, Ta-Poly1 , Ta and finally Al and polyethylene. But in this case, the weight of the polyethylene is better than other materials. The Al, Ta-Poly2, Ta-Poly1, W-Poly2, W-Poly1 and finally Ta and W come after polyethylene [9].

CONCLUSION

According to the simulations and calculations to reduce the effects of space radiation and the results, the flux which satellite encounters during passing through the radiation belts changes according to altitude and orbital inclination intensively. Flat mode in Geant4 and Fluka software, in addition to less estimated dose it estimates less thickness of the shield for electronic components. Result of the optimization process is not the same as in spherical and flat. In both spherical and flat shield, combining light and heavy materials as space radiation shielding in space is more appropriate option. According to studies done on the results of radiation test in some microelectronics devices, has been determined that the defect of the most electronic components, is about 2-20 Krad for TID effect and the DDD effect is about 2×10^{10} flux of protons 10 Mev.

REFERENCES

[1] Adams L., *IEEE - Trans on Nuclear Science*, **1996**, 43, 1014.
[2] Bhowmik S., and Benedictus R., Applied Electromagnetics Conference, AEMC IEEE, **2007**, p 1- 4.
[3] ECSS-E-ST-10-12C, ESA's standards, Noordwijk, The Netherlands 20/10/05.
[4] Featherby M., "Advanced Conformal Coating for Radiation Shielding of Microelectronics for Space",Maxwell Technologies Microelectronics Co., **1999**.
[5] Margaret R., *IEEE Trans. On Nuclear Science*, **1996**, 43, 2665.
[6] NASA practice NO.PD-ED-1258, "Space Radiation Effects on Electronic Components in Low-Earth Orbit", **1996**, PAGE 1 - 7.
[7] Parker E.N., *Space Weather*, Vol. 3, S08004, null pp., **2005**.
[8] Poivey C., "Radiation Hardness Assurance for Space Systems", NASA GSFC, **2003**.
[9] "Polyrad Performance Data Sheet", Long Hill Technologies Inc., **2000**.
[10] US patent NO. 5998867, Ronald J. Jensen, "Radiation Enhanced Chip Encapsulatant", **1999**.
[11] Wilson J.W., Cucinotta F.A., Miller J., Shinn J.L., Thibeault S.A., Singleterry R.C., Simonsen L.C., and Kim M.H., NASA , *Mat. Res. Soc.Symp. Proc.*, **1999**, pp. 551; 3-15.
[12] Ferrari A., et Al., "Fluka: a multi-particle transport code," CERN-2005-010 (**2005**).
[13] Santinb G., Nieminen P., Evansa H., Daly E., Lei F., Truscott P.R., Dyer C.S.,Quaghebeur B. and Heynderickx D, *Nuclear Physics B.*, **2003**, pp. 69-74.
[14] X-5 Monte Carlo Team, "MCNP-A General Monte Carlo N-Particle Transport Code", Los Alamos National Laboratory, April **2003**.