Studying the Total Ionizing Dose and Displacement Damage Dose effects for various orbital trajectories

S.W. Samwel\(^1\), A.A. Hady\(^2\), J.S. Mikhail\(^1\), Makram Ibrahim\(^1\) and Y.S. Hanna\(^1\)

\(^1\)National Research Institute of Astronomy and Geophysics (NRIAG), Helwan, Egypt
samwelsw@nriag.sci.eg

\(^2\)Faculty of Science, Cairo University, Giza, Cairo, Egypt
e-mail: aahady@yahoo.com

Abstract. The impact of radiation effects is growing more critical with the advent of newer technologies in space. The effects which are important to consider for spacecraft design fall into two categories, long term effects expressed in the Total Ionizing Dose (TID), Displacement Damage Dose (DDD), and the short term effects expressed in Single Event Effects (SEEs). Only, the long term effects will be discussed for the present work, in which, a comparative study of the TID and DDD for various orbital trajectories has been carried out. It is found that the level and type of hazard depend, to a great extent, on the orbit of a given spacecraft. Both TID and DDD levels vary widely with varying altitude and inclination and that the Geo-Transfer Orbit (GTO) experiences the most intense doses of both effects in comparable to other spacecraft in other orbital trajectories.

Keywords. Total Ionizing Dose (TID), Displacement Damage Dose (DDD), Single Event Effects (SEE), Non Ionizing Energy Loss (NIEL), orbital trajectories.

1. Introduction

Space radiation causes harmful effects on materials used in satellites. These materials are required to withstand degradation due to this radiation over the mission lifetime of a satellite [Jun 2001, Johnson 2000]. The most common effects against which a satellite should be protected are total dose, displacement damage, and single event effects. The main objective of the present work is to study the interaction of the space energetic charged particles with materials onboard spacecraft for different orbital trajectories. Section 2 discusses the total ionizing effects on silicon (as a target material) for different orbital trajectories. Section 3 focuses on the displacement damage effects and estimates their doses on silicon as a target material for different orbital trajectories. Thus, only the trapped and solar particles environments are considered as an input in this study. Finally, a summary of the results obtained for the different classes of orbits will be presented as conclusion in section 4.

2. Total Ionizing Dose as computed for different orbital trajectories

In the present section, the total ionizing doses attributed to the trapped and solar particles for different orbital trajectories are investigated for a one year mission length (during the solar maximum) starting at the orbital epoch 1998, July, 01 using SHIELDOSE 2 model [Seltzer 1994] and presented in figure (1). The inclination, perigee and apogee of the representative orbits are summarized in table 1. The figure declares that...
Table 1. The inclination, perigee, and apogee of the representative orbits

<table>
<thead>
<tr>
<th>Orbit</th>
<th>Inclination</th>
<th>Orbital perigee</th>
<th>Orbital apogee</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEO</td>
<td>28.4°</td>
<td>597 km</td>
<td>618 km</td>
</tr>
<tr>
<td>Polar</td>
<td>98.5°</td>
<td>724.7 km</td>
<td>839.3 km</td>
</tr>
<tr>
<td>MEO</td>
<td>56.2°</td>
<td>19988.6 km</td>
<td>20375 km</td>
</tr>
<tr>
<td>GEO</td>
<td>0.0405°</td>
<td>35774.7 km</td>
<td>35797.8 km</td>
</tr>
<tr>
<td>GTO</td>
<td>18.0115°</td>
<td>338.5 km</td>
<td>34536.5 km</td>
</tr>
</tbody>
</table>

The small changes in the altitude or the inclination angle of the spacecraft orbit can lead to drastic changes up to three orders of magnitude in the total dose deposited inside a spacecraft during a mission. In addition, it is clarified that a spacecraft in a GTO experiences the most intense deposited ionizing doses. The total dose sustained in space environments are almost exclusively attributed to trapped particles contained in the radiation belt and to protons emitted by solar flares. Therefore, figure 2(a, b, and c) is plotted to represent the influence of the altitude and inclination on the trapped protons, electrons, and solar proton doses, respectively, as individuals, in rads of Si which would be received by spacecraft at various orbital trajectories for one year mission length. The figures show that both protons and trapped electrons have sufficient energy to penetrate the skin of a spacecraft. However, the trapped electrons can be easily shielded in comparable to protons. This may refer to the fact that the trapped electrons are much less energetic than protons and consequently are easier to shield against. On the other hand, figure (2) represents that a spacecraft in a LEO orbit experiences no solar proton doses while another in a GEO orbit experiences no trapped proton doses. In addition, figure (2a) clarifies that a spacecraft in a MEO orbit experiences only low trapped proton doses which may refer to the fact that the energetic trapped proton population is confined to altitude below 20,000 km, while lower energy protons cover a wider region with protons of energies below 1 MeV reaching Geostationary altitudes [Meusel et al. 2005, Samwel et al. 2006].

Figure 1. Total ionizing dose-depth curves for various orbits around Earth for 1 year mission length.
The displacement damage energy deposition can be calculated if the non-ionizing energy loss (NIEL), and the particle spectrum are known in the region of interest. In the present study, the NIEL is calculated in units of MeV/g using the NEMO 2.0 code developed by ONERA and included in OMERE 3.1 code [Inguimbert et al. 2005]. Although the fluxes of electrons are not negligible, their NIEL’s are orders of magnitude smaller than that of protons [Jun 2001]. Therefore the displacement damage calculation in our problem concentrated on the effects of protons. Figure (3) plots the total Displacement Damage Dose in MeV/g(Si) as a function of the Aluminum shielding thickness for varies orbital trajectories for one year mission length. The figure clarifies that the small changes in the altitude and inclination of the spacecraft orbital trajectories can lead to extreme changes in the displacement damage doses up to 5 orders of magnitudes. Besides, it appears that a spacecraft in a GTO orbit experiences the most intense displacement damage doses in comparable to other spacecraft in other orbital trajectories understudy.

As it is mentioned that the displacement damage are almost solely attributable to the trapped and solar protons, thus, figure 4(a and b) is plotted to represent the influence of the altitude and inclination of the spacecraft orbital trajectories on the displacement damage dose attributed, respectively, to the trapped and solar proton for one year mission length with the same orbital altitudes and inclinations mentioned in section (2), respectively. The figures clarify that the displacement damage doses attributed to trapped and 

3. Displacement Damage Dose as computed for different orbital trajectories

Figure 2. Ionizing doses attributed to (a) trapped protons, (b) trapped electrons, and (c) solar protons, for Si as a target material, for various orbital trajectories for 1 year mission length.

Figure 3. Total Displacement Damage Dose (DDD) curve as a function of aluminum shielding thickness for various orbits for 1 year mission length.
solar protons, vary widely with varying orbital altitude and inclination, especially for the trapped protons which show drastic changes in their displacement damage doses up to five orders of magnitude deposited inside spacecraft during a mission.

![Figure 4. Displacement damage Dose (DDD) curves attributed to, (a) trapped protons, (b) solar protons, as a function of spherical aluminum shielding thickness for different orbital trajectories](image)

4. Conclusion

In the present work, we have carried out comparative studies of the Total Ionizing Dose (TID) and displacement Damage Dose (DDD) for different orbital trajectories. Included in, the TID attributed to trapped protons, electrons and solar protons and DDD attributed to the trapped and solar protons. The SHIELDOSE-2 model is used to estimate the TID while the DDD is calculated by integrating the fluence over the NIEL values of the target material for different orbital trajectories. Based on the previous comparisons, several conclusions can be deduced

1- TID and DDD levels vary widely with varying orbital altitudes and inclinations.
2- A spacecraft in a GTO orbit experiences the most intense doses from both TID and DDD in comparable to other spacecraft in other orbital trajectories.
3- A spacecraft in a LEO orbit experiences the lowest doses from both TID and DDD.
4- A spacecraft in a GEO experiences neither TID nor DDD.
5- A spacecraft in a LEO experiences neither TID nor DDD from trapped protons.
6- A spacecraft in a GEO experiences neither TID nor DDD attributed to trapped electrons can be easily shielded against, while protons (both solar and trapped) are extremely penetrating and are hardly affected by even the heaviest shield.

References

Jun, I. 2001, IEEE Transactions on Nuclear science, 48, 1, 162.
Johnson, A.H. 2000, The 4th International workshop on radiation effects on semiconductor devices for space application, Tsukuba, Japan.
Inguimbert, C., Gigante, R. 2005, RADECS workshop, September, Cap d’Agde FRANCE.