Space Environment and Evaluation of Typical High Altitude Satellite

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Abstract :

The space environment consists mainly of high-energy charged particles, such as protons, electrons and heavy ions. They are originating from several sources including galactic cosmic radiation, solar flares and van Allen belts. High energy electromagnetic radiation and neutrons have also been measured on spacecraft. Although shielding can reduce the effect of space radiation it cannot be eliminated completely. So the proper evaluation is the key to improve the system performance in space environment. In this paper, the space environment analysis and evaluation for High Altitude Satellites reported with an emphasis on radiation analysis as being the most significant source of space product failures. When there is no shielding, the forecasted value of Total Ionizing Dose (TID) is 10^9 rads (Si) and non-ionizing Displacement Damage Dose (DDD) is 10^{14} MeV/g(Si) for 18-year mission lifetime of high altitude satellite.

Keywords: Satellites, TID, DDD, Space environment, Radiation.

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1. Introduction

The space radiation environment can lead to harsh conditions for electronic systems. The characteristics of the radiation environment are dependent on the date of the operation, its duration and the orbit of the mission. These parameters determine the aging of the components and their electrical performance. So, hardness assurance is needed to ensure that electrical performance during the system life is achieved. Some Precautions should be considered in order to produce a system tolerance against the radiation environment.

2. Literature Review

we report space environment analysis for High Altitude Satellite which is known to be radiation violent environment and thus hazardous for space electronics.

space environment of an item is a set of environmental conditions (e.g. radiation, micrometeoroids, space-debris) defined by the external physical world for the given mission[1].

Incident particles include contributions of protons, electrons, galactic cosmic ray heavy ions and particles from solar events (protons and heavy ions) and have the following components[2]:

1. particle levels outside of spacecraft to evaluate surface damage including trapped protons, electrons, solar protons.
2. particle levels inside spacecraft to evaluate displacement damage, Ionizing Dose and appraisal effectiveness shielding include trapped protons, electrons, solar protons and secondary particles.

These energetic particles can penetrate surfaces of spacecraft. This is typically above 100 keV for electrons and above 1 MeV for protons and ions.

The effect of protons is more dominant in low orbits, whereas electrons have a larger influence in higher orbits [3]. Table I shows dominated particles and their energy in related orbits.

Table 1: Technical illustration of Satellite [4]

Particle	Energy
Surface Charging	0.01 - 100 keV
Total Ionizing Dose	>100 keV
Single Event Effects	>10 MeV
Displacement Damage	>10 MeV

For every application there are various radiation hardness levels with respect to mission properties. So, for all components and units to achieve appropriate radiation resistant levels should be considered for radiation hardening. It is in fact a series of design considerations to make components and systems resistant against damages caused by space radiation. These radiation resistant levels have been shown in Table II, for different application.

Table 2:
Technical illustration of Satellite [5]

Radiation Resistant Level	Application
0-3 Krad	Commercial
20-50Krad	Space low earth orbit
50-200Krad	Space high orbit
Over 200Krad	Deep space

In this work, we computed "orbit generator" algorithm in order to define geosynchronous directly above the earth equator (0^0 latitude) route at ~36000 km for 18-year length of mission. Table III. represents the list of orbital parameters for this project.

Table 3:
HIGH ALTITTUDE SATELLITE SIMULATED orbital parameters

Orbit Type	Parameters
Altitude	36000 Km
Inclination	0°
Orbit start	2012
Segment end	2030
Segment length	18 years

Considering the mission period of RASAT, we have simulated the maximum solar radiation of the space environment to model the worst case scenario. For these simulations, NASA's latest edition of proton AP-8 [6] and electron AE-8 [7] flux models have been used. ESA's Space Environment Information System (SPENVIS) and OMERE are adopted for the simulations and radiation space modeling.

Due to their large energy coverage, trapped particles lose their kinetic energy in different mechanisms and create various effects on the spacecraft.

In this paper, base on space requirements in space radiations scope. These parameters include:

1. Total Ionizing Dose (TID) is the amount of deposited energy per unit mass of material by ionizing radiation. It is mainly caused by protons. TID may cause drift in parameters of the active electronics.
2. Single Event Effect (SEE) is an immediate failure mechanism.
3. Displacement Damage Dose (DDD) is modification of the atoms in the lattice by neutrons, protons, secondary particles and heavy ions.

we calculated 50-krad (Si) total ionizing radiation with a 2 mm shielding of Al for 18-year.

In section II of this paper, analytical results have been that electrons are screened effectively by increasing the thickness of shielding compared to protons.

In this paper, section II reviews the Radiation resilient components of space environment. Section III evaluates potential effects and disorders caused by space environment. Section IV estimates total ionizing dose, displacement damage flux for 18-year mission length of High Altitude satellite. Finally, in section VI we show an effective solution for designing appropriate shielding in satellite.

2.1. Allowable Radiation Dose for Satellite Components

Recognizing the allowable radiation dose for every subsystem which is used in a satellite is essential. These dose levels are achieved from related datasheets in space specification components. In commercial off-the-shelf (COTS) circumstances, these are obtained from the materials and manufacturing processes of components and the previous operational experiences.
Many of the hardened technologies are no longer available due to the physical mechanisms that cause total-dose-induced failure; hence more commercially off-the-shelf components are being used. This situation presents a challenge for system designers, since the commercial parts typically have lower failure levels and larger variability in response. Table IV presents allowable radiation dose for the main units and subsystems for this simulation.

Table 4:
ALLOWABLE DOSE FOR EVERY SUBSYSTEM

Sub system	*Accept level of Dose(Krad)*	*Shield thickness required(mm) (Worst Case)*
Mixer	*<100*	*~1.04*
Low Noise Amplifier(LNA)	*50<TID<300*	*~1. 4*
Phase lock oscillator (PLO)	*<100*	*~1.04*
Oven-Controlled Crystal Oscillator (OCXO)	*<100*	*~1.04*
Travelling Wave Tube Amplifier(TWTA)	*40<TID<100*	*~1.53*
Power Supply	*25<TID<100*	*~2.02*
Digital Controller	*<300*	*~ 0*
A/D	*<1000*	*Without Shielding*

2.2. Dose Radiation Calculation Base Shield Thickness

In this section mathematical model for computing radiation energy in different subsystems is considered. First, our assumption is only thickness variation of the absorber. [8].

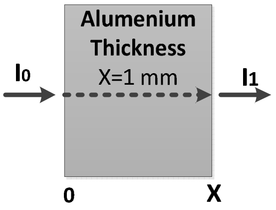


Fig. 1: Aluminum thickness of absorber

Due to this assumption, i.e. only the thickness of the absorber is changed, magnitude of ΔI should be dependent on the radiation intensity as well as the thickness of the absorber. In equation (1), that is for an infinitesimally small change in absorber thickness:

$$-dI \propto I.dx \qquad (1)$$

In equation (2), the minus sign indicates that the intensity is reduced by the absorber. Turning the proportionality in this equation into an equality, we can write:

$$-dI = \mu I.dx \qquad (2)$$

where the constant of proportionality, μ, is called the coefficient. Dividing across by I the equation can be reformatted as:

$$\frac{-dI}{I} = \mu.dx \qquad (3)$$

Equation (3) describes the situation for any tiny change in the absorber thickness, dx. To find out what happens for the complete thickness of an absorber we simply add up what happens in each small thickness. In equation (4),we integrate the above equation from x = 0 to any other thickness x, the radiation intensity will decrease from I_0 to I_x, so:

$$-\int_{I_0}^{I_x} \frac{dI}{I} = \int_0^x \mu.dx \qquad (4)$$

Equation (5),mentions that the radiation intensity will decrease in an exponential fashion with the thickness of the absorber with the rate of decrease being controlled by the linear attenuation coefficient.

$$I_x = I_0.e^{-\mu x} \qquad (5)$$

In Fig 2, we compute I_x for two layers and show 1 mm of (AL) thickness is equivalent to two 0.5 of mm(Al) thickness layers.

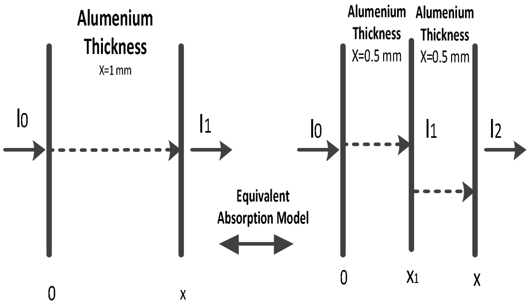


Fig. 2: Absorption thickness base Decomposition process

$$I_1 = I_0 . e^{-\mu} \text{ For } x = 1 \text{ mm(AL)} \tag{6}$$

we decompose shielding to two 0.5 mm(AL),we have:

$$I_1 = I_0 . e^{-0.5\mu} \text{ For } x = 1 \text{ mm(AL)} \tag{7}$$

$$I_2 = I_1 . e^{-0.5\mu} \text{ For } x = 1 \text{ mm(AL)} \tag{8}$$

Now, we know total absorption thickness is equivalent to :

$$I_2 = I_1 + I_0 = [\![(I]\!]_0 . e^{-0.5\mu}) . e^{-0.5\mu} = I_0 . e^{-\mu} \tag{9}$$

2.3. Space Environment Effects for High Altitude Satellite

Dose and dose-rate are effective factors in space missions. In space applications, radiation dose absorbed per unit of time is equal to dose rate. A radiation dose rate can be set at some particular unit of time and would be called radiation dose rate [9].

Space radiation has a low dose rate of ~10^{-4} to ~10^{-2} rad/s, however several years of mission duration accumulates large amount of radiation doses, which becomes a crucial threat for space electronics subsystems. Energetic ions, predominantly from cosmic rays and solar flares, lose energy in materials by ionization. This energy transfer damage memory elements by creating highly localized ionization.

In most cases, (Al) shielding (is an appropriate solution because they are resistant to radiation penetration. In this paper, we apply a Honey Comb structure which uses to quantify effects of spot shielding on components and self-shielding in active antenna arrays (Fig.3).

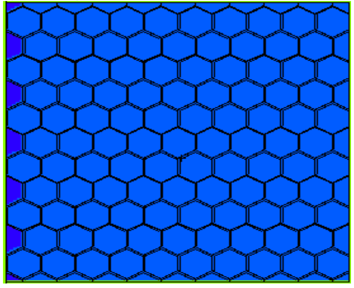


Fig. 3: Honey comb shielding

The system provides an online interface to the space environment models and its potential influences. For the analysis, 18- year mission length is selected and orbital elements are constructed by orbit generator code of OMERE v3.3 software which computes the space environment and the radiation effects on your electronic equipment in terms of Dose, Displacement Damage Dose and Single Event Effect and so[10].

NASA's radiation belt models for proton AP-8 and electron AE-8 are utilized as the standard models for space engineering. Energy range for protons is from 0.1-400 MeV and for electrons from 0.1-7 MeV. We applied both models as designated by ECSS-E-ST-10-04C [11] standard of space environment into our model.

Fig. 4 shows Electron and Proton fluxes, which is illustrated for High Altitude Satellite averaged 36000 km orbit.

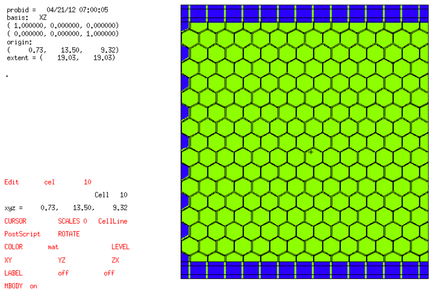
The ionizing doses are calculated isotropic as a function of sphere radius using SHIELDOSE-2 code [11,12].

Aluminum and Silicon are considered as shielding layer and target material, respectively. An effective approach is to utilize a spacecraft specific shielding definition to calculate total dose and particle levels at specific locations inside the spacecraft. As shown in Fig. 5, total doses for different Aluminum shielding thicknesses are calculated. These total doses are created by primary particles.

As can be seen, Total Dose is approximately 10^9 Rad. This allows the radiation effects engineer to specify a requirement based on a nominal effective spacecraft shielding (such as 70 mills Al for External surface) using a generic geometry(such as solid sphere).

The design details of the spacecraft indoor satellite are obtained with respect to Eq. (5) and Fig. 3. In this solution radiation energy is reduced from 1Grad in outer environment reach to 50 Krad. all of space components have RDM(Radiation Design Margin) equal 2 which it means twice resilient radiation level Under the sub system together[13].

we use a 1 mm(AL) thickness Consistent with a Honey comb structure is Fig.6.



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probid =   04/21/12 07:00:05
basis:   XZ
( 1.000000, 0.000000, 0.000000)
( 0.000000, 0.000000, 1.000000)
origin:
(     0.73,    13.50,     9.32)
extent = (    19.03,    19.03)

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Edit       cel        10
                            Cell   10
xyz =     0.73,    13.50,     9.32
CURSOR          SCALES 0   CellLine
PostScript      ROTATE
COLOR      mat                 LEVEL
XY              YZ             ZX
LABEL           off          off
MBODY  on
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Fig. 6: Honey Comb Structure

In Fig.7, we show radiation level in different level for High Altitude Satellite.

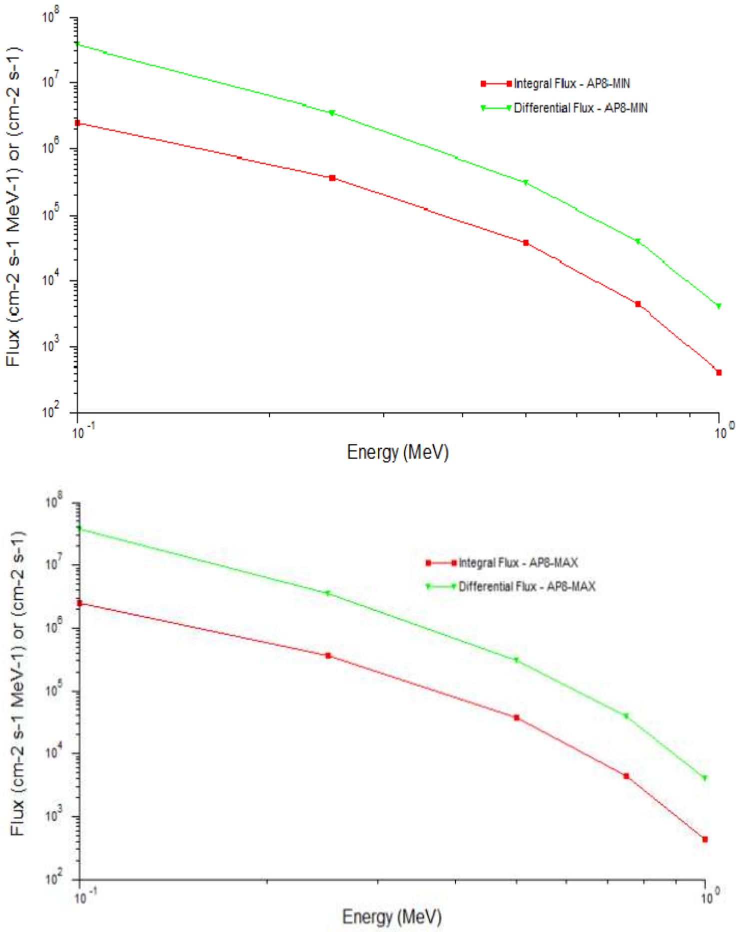

Fig. 4: AP-8 and AE-8 flux for HIGH ALTITTUDE SATELLITE

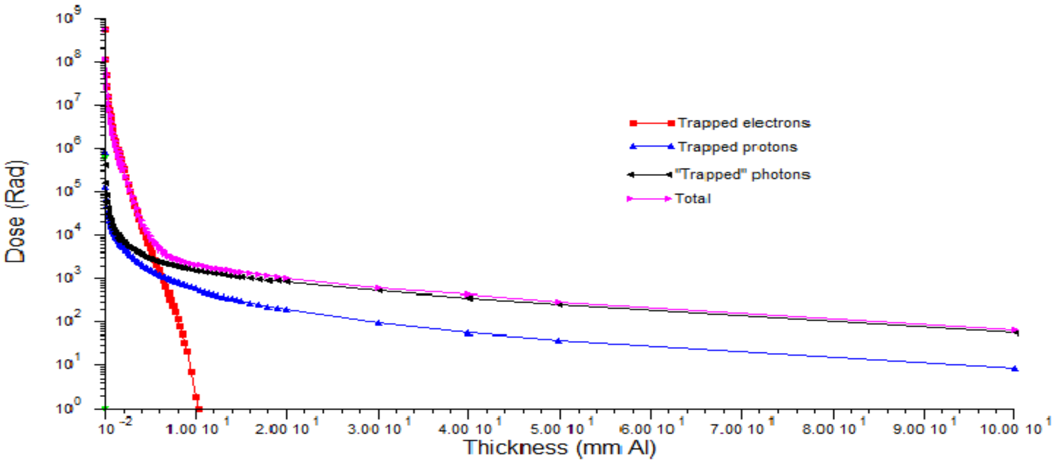

Fig. 5: Total mission dose (rad) for different Aluminum shielding thickness for High Altitude Satellite

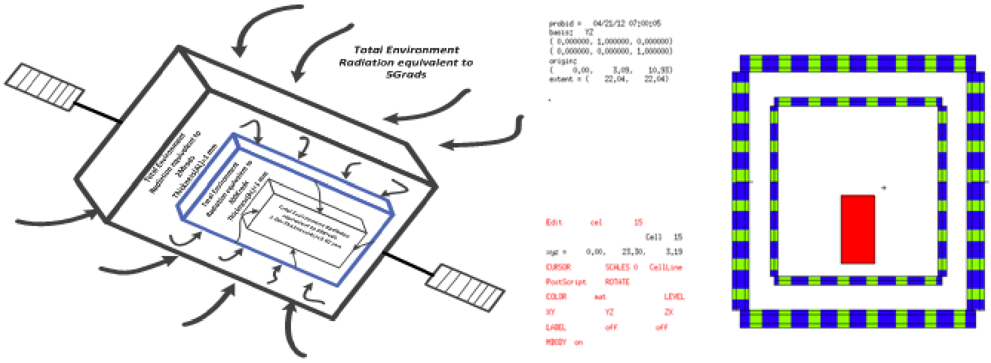

Fig. 7: Reduction steps of radiation for 18-year mission length of HIGH ALTITTUDE SATELLITE

It must be emphasized that although some types of devices are guaranteed to withstand total dose levels above 200 krad(Si),they may fail at far lower levels when they are in various thicknesses. In Fig.8, we radiation levels were low enough so that proton displacement damage on electronic systems was a second order problem. Also, devices that had been tested for displacement damage has shown on relative insensitivity to this effect [14]. Because of this, nearly all radiation testing has concentrated on ionization damage.

that increasing shielding thickness to improve Displacement Damage Dose (DDD) protection is effective over ~1 mm of Al. we design a effective shielding nearby 2 mm of Al for overall satellite .
The space environment is analyzed and evaluated for 18-year mission period and 36000 km orbit of High show dose value versus thickness (Al) base Honey comb shielding.
For most NASA missions the

Therefore, testing for RHA of optical-couplers must go beyond traditional total ionizing dose (TID) tests.
Shielding has some effect, but it depends on location of the device.
Simulation clearly indicates how increasing aluminum shielding easily decreases the effects of electrons and protons on the satellite surface. The analysis also implies
Altitude Satellite. Total ionizing dose is estimated to be 50 Krad for inner level of satellite where components should not be less than specific resilient radiation level(50 Krad). We found that electrons and protons are easily mitigated by increasing Al shielding thickness, over 5 millimeters.

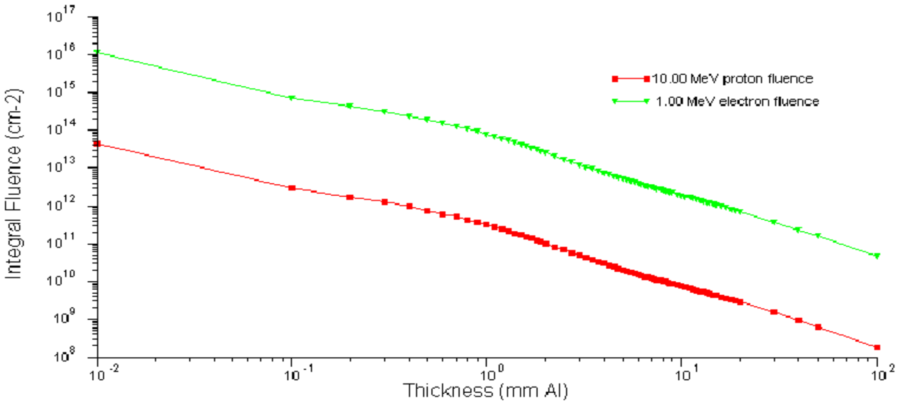

Fig. 8: Displacement damage curve for 18-year mission length of High Altitude Satellite

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