Radiation Analysis of Communications and Broadcasting Satellite

Jaewoo Park*, Taejin Chung*, Seong-Pal Lee*
Communication Satellite Development Center, Radio & Broadcasting Laboratory
Electronics and Telecommunications Research Institute, Daejeon, Korea, 305-350

Jongho Seon, Yun-Whang Jeong****
SaTReC*i*, 13F Sahak Bldg., Dunsan, Seogu
Daejon, Korea, 302-120

Abstract

A radiation analysis is performed for the Ka and Ku-band transponder of the Communications and Broadcasting Satellite (CBS) that is planned for launch into the geo-synchronous orbit. A particular attention is given to calculation of Total Ionizing Dose (TID) for the mission life time of 15 + 3 years. A numerical modeling of the charged particles at the geo-synchronous orbit is undertaken. The charged particles from the modeling are then transported through the mechanical structure and component housings of the transponder. A set of locations are selected for the detailed calculation of TID. The results from the present calculation show that three-dimensional modeling of the component housings as well as the mechanical structure of the spacecraft is requisite in order to acquire a reliable calculation of TID.

Key Words : Radiation, Total Ionizing Dose, Communication Satellite

Introduction

The design of a communication satellite at geo-synchronous orbit requires an estimate for a radiation dose from charged particles in the Earth's magnetosphere because the electronic components in the satellite will acquire damage from the particles. The radiation environment consists of electrons, protons, and heavy ions that are either trapped by the Earth's magnetic field or directly penetrating from the interplanetary space. Figure 1 shows a brief description of Earth's radiation environment and its relative location with respect to the Earth's magnetic field. A comprehensive summary of the Earth's radiation environment is available[1]. Various responses of the electronics to the radiation environment are found. Such effects include Total Ionizing Dose (TID) that is a cumulative effect due to the excitation of electron-hole pairs at the biased junction of the semi-conductor, Single Event Effect (SEE) that is due to the collection of charged particles behind a passage of highly ionizing, high-energy particles, and displacement damage that is due to the displacement of nucleus of the lattice by the collision with high-energy particles. A review of such effects is also widely available in the literature [2]. The purpose of this paper is to present a calculation of TID for the Ka and Ku-band transponder of the CBS that is being developed by Electronics and Telecommunications Research Institute (ETRI) [3]. A description of numerical modeling of the radiation environment will be given in

* Principal Researcher
E-mail : pjw@etri.re.kr, TEL: 042-860-5634, FAX: 042-860-6949
** Senior Researcher

the next chapter. Then radiation transport through the shielding structure and discussions of the results will follow.

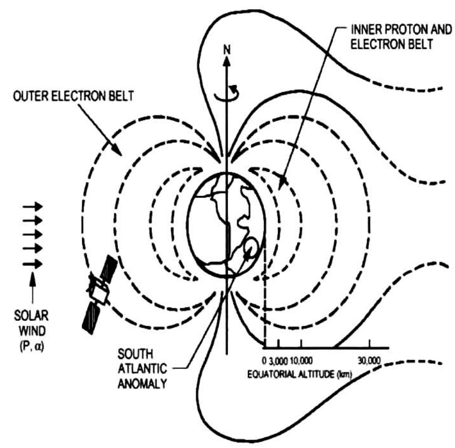

Fig. 1. Radiation Environment of Earth

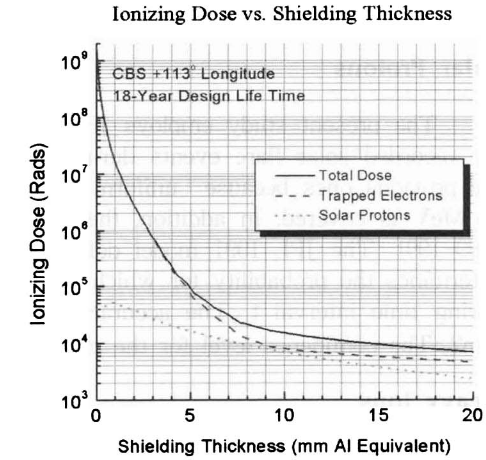

Fig. 2. Dose-Depth Curve of CBS

Radiation Environment

Orbit

The satellite is planned for launch in the near future. The orbital characteristics of the satellite is summarized in the following table.

Table 1. Orbit elements of CBS

Orbit Element	Value
Latitude	0^{o}
Longitude	113^{o} East
Altitude	35,800 km
Mission Life time	18 years

Trapped Electrons and Protons

The trapped particle models that are employed in the present analysis are AP-8 and AE-8. Their characteristics are as follows. The trapped electron model in the present study that is to quantify the trapped electrons distributions is AE-8 MAX. This model is expected to conservatively estimate the trapped electrons in the year 2004-2005 in which CBS is expected to be launched. The model is empirical and based upon collected data during 1975 (Solar Minimum) to 1980 (Solar Maximum). The difference between AE-8 MIN and AE-8 MAX occurs mainly below altitude height of about 1000 km. The model is parameterized with the distance of the magnetic field lines in the magnetic equator and is sensitive to the strength of magnetic field. The sensitivity of the model becomes higher at altitudes below 1000 km with respect to the altitude and geomagnetic fields. One needs to be cautious that the model does not take into account the time dependence of the charged particles and covers energy range of 0.04 MeV < E< 7 MeV. The trapped proton model in the present study is AE-8 MAX. The model is empirical and based upon collected data during 1975 (Solar Minimum) to 1980 (Solar Maximum). The difference between AP-8 MIN and The present study employs JPL 1991 model for solar protons. JPL model is based upon the recorded solar flare events during 1963 to 1991. The model is expected to be superior to the previous ones because uniform data sets are used and a wide energy range of 1 MeV ~ 60 MeV is covered. In addition, the model includes major solar events in August of 972 and 1989-1991. The JPL 1991 model defines five functions P[i](F,t) at 1, 4, 10, 30, 60 MeV that determines the probability for which the integral fluence exceeds the threshold fluence F(>E(i)) during time interval t. The accuracy of the model decreases for small fluence less than 109

/cm2. The confidence level for the present study is 90%. AP-8 MAX occurs mainly below altitude height of about 1000 km. The model covers energy range of 0.1 MeV < E< 400 MeV. Figure 2 illustrates spatial distribution of trapped protons and electrons.

Solar Protons

The present study employs JPL 1991 model for solar protons. JPL model is based upon the recorded solar flare events during 1963 to 1991. The model is expected to be superior to the previous ones because uniform data sets are used and a wide energy range of 1 MeV ~ 60 MeV is covered. In addition, the model includes major solar events in August of 972 and 1989-1991. The JPL 1991 model defines five functions P[i](F,t) at 1, 4, 10, 30, 60 MeV that determines the probability for which the integral fluence exceeds the threshold fluence F(>E(i)) during time interval t. The accuracy of the model decreases for small fluence less than 109 /cm2. The confidence level for the present study is 90%.

Heavy Ions

The heavy ion model for the present study is CREME. CREME includes galactic cosmic radiation (GCR), solar energetic particle, and anomalous components. CREME covers both the solar minimum (higher flux) and solar maximum (lower flux). The present study employs a 90% worst case. In other words, statistically 9 out of 10 solar flare has a lower intensity than the present study. The anomalous component corresponds to a lower-energy portion of the cosmic radiation and is observed mainly during minimum solar activities. The CREME covers a charge range of Z=1 to Z=92 and a energy range of E=0.1 MeV/n to 100,000 MeV/n.

Shielding

Isotropic Shielding

In the previous section the environment for space radiation is defined. The first shielding analysis is performed based on an assumption that a uniform thickness over 4π ster-radian solid angle is maintained with respect to the calculation point. The assumed material for the shielding is Aluminum. The output of the analysis is the Dose-Depth Curve that is TID as a function of shielding thickness. The curve is used in Phase II and Phase III analysis. The Dose-Depth curve that is obtained from Phase I is found in Figure 3. The curve covers a thickness range of 0-20 mm with a binning thickness of 0.1 mm. In addition, the effects from trapped electron, trapped proton, and solar protons are separately considered and their sum is also included. The effect from heavy ion is not included because of their negligible contribution to TID. The effect of the trapped proton is not shown in Figure 2 because of their negligible magnitudes. The figure shows that the trapped electrons mainly determine TID. A small fraction of TID is contributed by solar protons. The figure also shows that the effects of shielding is increased by adding more thickness, but it is difficult to get TID less than 10 kRad.

Mechanical Structure

To simulate the CBS spacecraft platform for the transponders, LM A2100A is considered. The platform is chosen because it is a commercial platform that has been adapted from KOREASAT-3 and is likely to be chosen for CBS. Figure 3 and Table 2 show the structures of CBS that are considered for the present analysis.

The current analysis simplifies the mechanical design of the payload component housings for faster and efficient calculation of effective shielding thickness. A particular attention has

Table 2. Mechanical Modeling Elements of LM A2100A

Mechanical Structures	Thickness (Al mm)
Base Panel	2
East Access Panel	2
Earth Panel	2
Internal Earth Panel	2
Internal North Panel	2
Internal South Panel	2
Internal West Panel	2
North Panel	2
South Panel	2
West Access Panel	2
East Oxidizer Tank	10
West Oxidizer Tank	10
Propellant Tank	10

been given to the simplification in order to preserve the overall effectiveness of the shielding geometry in the calculation. Figure 4 compares the real mechanical design of the payload with the simplified model. A set of calculation points are selected for the calculation of TID. The calculation points are representative locations of Channel Amplifier (ChAmp) - 0, 1, 2 and 3, Receiving Down Converter (RxDC) 0 and 1, and Local Oscillator (LO) 0 and 1 for the Ka-band transponder and ChAmp - 0. 1, 2, and 3, LO - 0 and 1, Intermediate Frequency (IF) Amp - 0 and 1 and Low Noise Amplifier (LNA) - 0 and 1 for the Ku-band transponder, respectively. A mechanical layout of the Ka-band transponder and a simplified model of ChAmp component housing. are also shown in Figures 5 and 6.

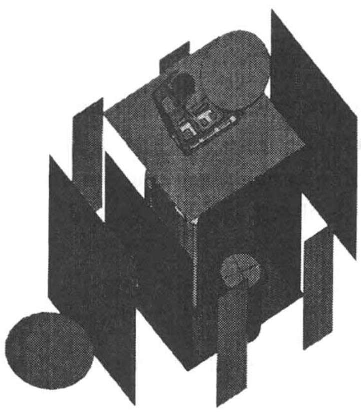

Fig. 3. Mechanical Modeling of CBS Platform based on Lockheed-Martin A2100A Platform

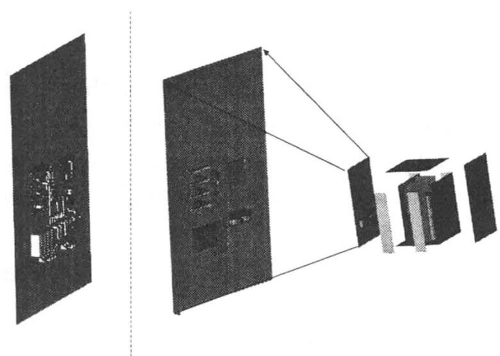

Fig. 4. Simplified Model of the Ka-band Transponder of CBS

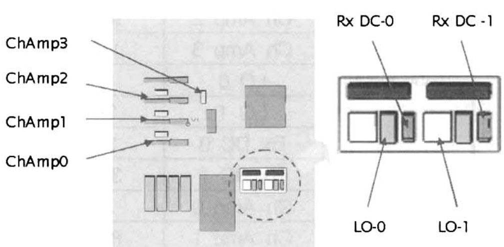

Fig. 5. Mechanical Layout of Ka-band Transponder

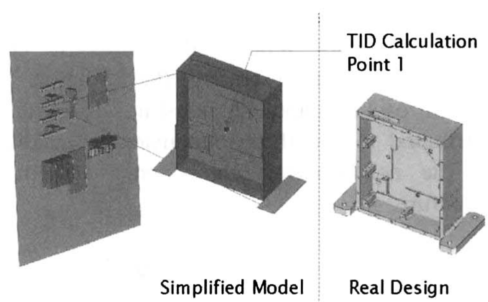

Fig. 6. Simplified Design of Channel Amplifier for Ka-transponder

Method of Spherical Sectoring

The shielding thickness of the CBS spacecraft platform or payload housing should be converted into the solid angle function with respect to the calculation point the in order to

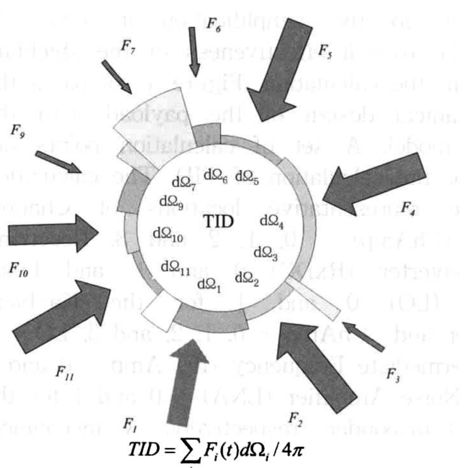

Fig. 7. Illustration of the Method of Spherical Sectoring

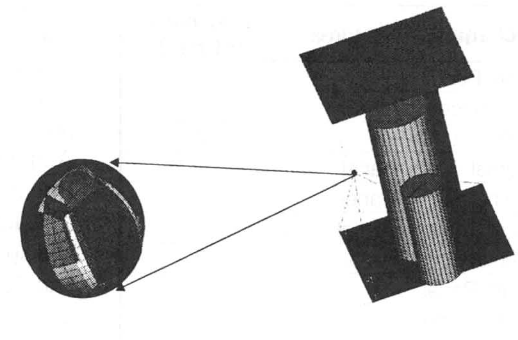

Fig. 8. Method of Spherical Sectoring Applied to CBS

estimate 3-dimensional shielding effect. That is to say,

$$TID = \sum_i Fi(t)\, d\Omega i / 4\pi \quad (1)$$

Here $d\Omega i$ is the solid angle of the i^{th} mechanical structure with respect to the calculation point, Fi is the total dose of the structure with effective shielding thickness t if the i^{th} structure covers full 4π solid angles. Figure 7 explains the method of spherical sectoring for the present study. The method applied to the CBS mechanical structure is illustrated in Figure 8.

Results

Table 3 summarizes the results of TID calculation for the selected equipments. Previously explained method has been applied to obtain the calculation. For each equipment, representative locations within the housings are selected for an investigation of spatial dependence of the TID levels. The results show that significant variations exist not only among the different equipment housings, but also among the different locations within each equipment housing. The variation is attributed to the three-dimensional shielding effect of the neighbouring components and mechanical structure.

Table 3. A summary of TID Calculation

Band	Equipment	TID (kRAD)
Ka Band Transponder	Ch Amp 0	89 - 114
	Ch Amp 1	83- 124
	Ch Amp 2	95 - 180
	Ch Amp 3	179 -181
	LO 0	24- 76
	LO 1	24 - 39
	Rx DC 0	28 - 88
	Rx DC 1	35 - 202
Ku Band Transponder	Ch Amp 0	75 - 98
	Ch Amp 1	85 - 105
	Ch Amp 2	86 - 112
	Ch Amp 3	99 - 189
	IF Amp 0	18 - 20
	IF Amp 1	17 - 22
	LNA 0	16 - 21
	LNA 1	16
	LO 0	38 - 67
	LO 1	35 - 110

Summary

A radiation analysis for the Ka and Ku-band transponder of the communication broadcasting satellite has been performed. Numerical modeling of the radiation environment is first undertaken followed by a three-dimensional modeling of the spacecraft structure and payload equipment housings.

Positional dependence of TID among the equipments and locations within the equipment are examined. Significant variations of TID with respect to the location of the equipment and locations within the equipment are found. The results show that the three-dimensional modeling of the equipment housings as well as the spacecraft structure is a requisite in the quantitative assessment of the TID.

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