CHARGING ANALYSIS OF
ENGINEERING TEST SATELLITE VIII (ETS-VIII) OF JAPAN

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Abstract

Large-scale geostationary satellite, ETS-VIII, is planned to be launched in 2003. As solar array panel with high voltage (100V) bus is introduced to ETS-VIII, the effect of spacecraft charging due to space plasma should be considered. Therefore, we conducted the charging analysis of ETS-VIII by using NASCAP/GEO. The maximum potential difference of about 2.9kV on the solar array panel of ETS-VIII was obtained in the worst space environment condition from the analysis. Although the potential of 2.9kV is possible to cause discharge, the influence to the satellite is thought to be small.

1. INTRODUCTION

Engineering Test Satellite VIII (ETS-VIII) of Japan will be launched by H-IIA rocket from Tanegashima Space Center of NASDA in 2003 [1]. Figure 1 shows the overview of ETS-VIII in orbit. In ETS-VIII, new technologies such as high voltage (100V) bus for high power supply and large-scale deployable reflector (LDR) are introduced to establish and verify the technology for the future large-scale spacecraft systems. Also, 25mN class ion thrusters are equipped on ETS-VIII to keep the north-south position. Although these subsystems and the main system are probable to be exposed to severe space environment, the systems must function normally during mission life.

Space plasma causes "spacecraft charging" to satellite. The spacecraft charging is possible to induce ESD (electrostatic discharge) damage to the satellite. Therefore the possibility should be verified at the design stage. Namely, charging analysis of the spacecraft should be carried out.

NASCAP (NASA Charging Analysis Program) /GEO is popular and useful tool to analyse the spacecraft charging [for example, 2, 3]. We also used it to evaluate the possibility of the occurrence of ESD on ETS-VIII in the severe space environment.

In this paper we will describe and discuss the results of the analysis.

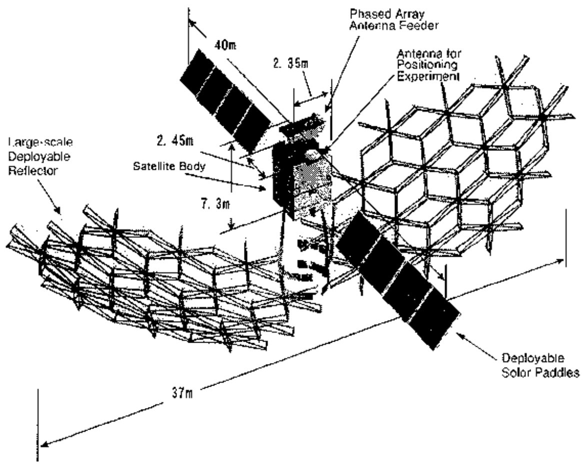


Fig.1 Overview of ETS-VIII in orbit

2. CONDITION OF NASCAP/GEO ANALYSIS

NASCAP/GEO analysis was conducted in the flow shown in Fig.2.

STEP 1: Definition of Model Shape

As the mesh space of NASCAP is limited to 17x17x33, we divided the satellite surfaces to the mesh as shown in Fig.3. In this model, we set the length of one side of the mesh as 2.5m from the limitation of the mesh space. In this figure, the sun is in +X direction. Two SAP's (Solar Array Panels) are always faced to the sun.

In Fig.3, the surface materials for the analysis are also shown. The surface materials are set as follows;

- CG (Cover Glass); the front surface of the SAP.
- CFRP (Carbon Fiber Reinforced Plastics); the rear surface of the SAP and the boom.
- ITO (Indium Tin-Oxide); Coated on OSR (Optical Solar Reflector) used for the south and north surfaces of the body of ETS-VIII.
- BK (Black Kapton); all surfaces except for the south and north surfaces of the body.
- GOLD (mesh of Gold); LDR.

The SAP is PLATE model. The front surface CG is always in sunlit condition and the rear surface is in shadow. As the LDR has the mesh structure knitted by fine strings made of gold, we defined it with PLATE model of MESH-ANTENNA made of GOLD. For the booms between the SAP and the body and between the SAP and the LDR, we used the rod-type BOOM. The body of the satellite is constructed by the cubic blocks of RECTAN.

STEP 2: Definition of Material properties

It is important to describe the parameter of the surface material precisely for valuable analysis. Table 1 shows the material parameters used for the charging analysis of ETS-VIII. As understood from this table, only CG is dealt with insulator and the other surface materials are conductive materials. As the conductivity of the insulator changes with temperature and it affects the charging characteristics, we used the conductivity of CG of $1.59\times10^{-13}\Omega^{-1}m^{-1}$ in sunlit condition (about 50ºC) and $1\times10^{-16}\Omega^{-1}m^{-1}$ in shadow (about –170ºC).

STEP 3: Definition of Plasma Environment

We defined the plasma parameters as double Maxwell distribution as shown in Table 2. This data of plasma environment is selected from the worst case data obtained by SCATHA satellite [4].

STEP 4: Definition of Optional parameters

In this step, the parameters such as the direction of the sun, the transmittance of the mesh antenna, the solar light intensity at the surface and the time step for calculation are set.

As the fine strings made of gold are used for LDR of ETS-VIII, the greater part of solar light is transmitted through the LDR. We defined the transmittance of solar light of the LDR as 0.73.

STEP 5:Calculation of Current Incident on Surface of Satellite

STEP 6: Calculation of Surface Potential

In these steps, the currents incident on the surface of the satellite at one time step and the surface potential at each mesh are calculated. And at next time step, the same calculations are repeated.

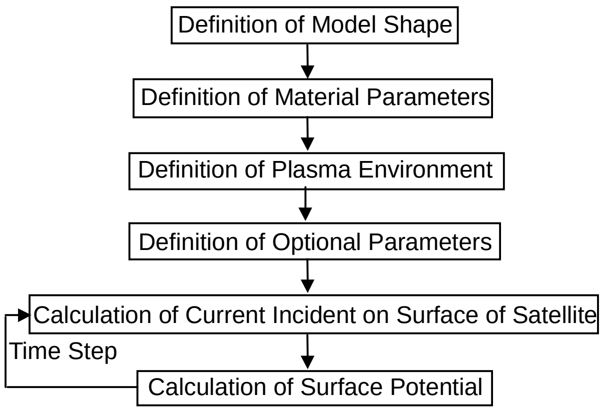


Fig.2 Flow chart of NASCAP/GEO analysis

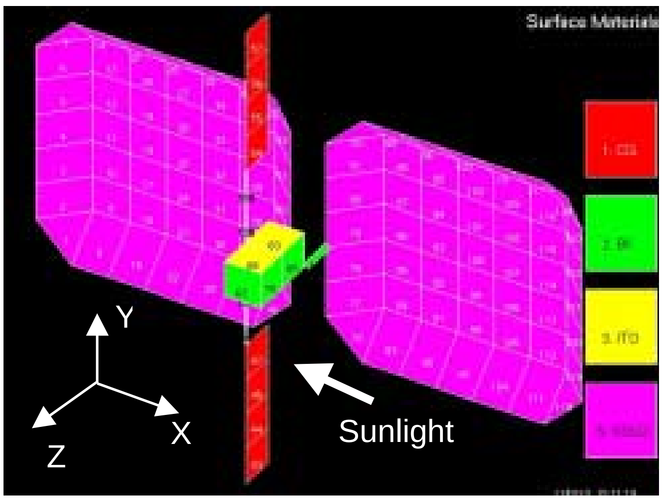


Fig. 3 Shape and surface materials of ETS-VIII for NASCAP/GEO analysis

Table 1 Material parameters used for NASCAP/GEO charging analysis

Parameter	Unit	CG	BK	ITO	CFRP	GOLD
Relative Dielectric Constant		7.4	3.5	1.0	4.3	1.0
Thickness	m	$1.0x10^{-4}$	$2.54x10^{-5}$	$1.0x10^{-6}$	$2x10^{-4}$	$4x10^{-7}$
Bulk Conductivity	$\Omega^{-1}m^{-1}$	*$1.59x10^{-13}$ **$1.0x10^{-16}$	-1	-1	-1	-1
Atomic Number	amu	18.7	4.5	24.4	5	42
Maximum Secondary Electron Yield for Impact Electron (δ max)		10	0.93	1.4	2.1	1.4
Primary Electron Energy at δ max	keV	0.35	0.28	0.8	0.15	0.8
Range Parameter 1	Å	-1	180	-1	-1	-1
Range Parameter 2		0	0.45	0	0	0
Range Parameter 3	Å	5.73	312	7.3	1.7	10.2
Range Parameter 4		41.2	1.75	55.5	1.77	96
Secondary Electron Yield Due to Impact of 1keV Proton		0.455	0.455	0.49	0.455	0.413
Proton Energy at Maximum Secondary Electron Yield	keV	140	80	123	140	135
Photoelectron Current Density Due to Normally Incident Sunlight	A/cm^2	$1.5x10^{-5}$	$7.2x10^{-6}$	$1.5x10^{-5}$	$4x10^{-6}$	$1x10^{-5}$
Surface Resistivity	Ω/cm^2	$2.5x10^{16}$	-1	-1	-1	-1

*:in sunlit condition, **: in shadow

Table 2 Plasma parameters in double Maxwell distribution of space plasma environment

		Energy (keV)	Density (cm^{-3})
Electron	Low energy	0.4	0.2
	High energy	27.5	1.2
Ion (Proton)	Low energy	0.2	0.6
	High energy	28.0	1.3

3. ANALYTICAL RESULTS

3.1 Quasi-static Analysis

We describe mainly the time dependence of the surface potentials of the insulating CG's on the satellite in the several positions in geostationary orbit. The CG on the SAP closest to the body is named as CG1 and the CG on the SAP farthest from the body is as CG4.

Our NASCAP analysis was done in only case of the vernal or autumnal equinox.

Figure 4 to Figure 7 show the potential histories of the conductive body and CG's on the SAP at four positions in orbit as follows.

(1) At dawn (local time, LT, 6:00)
(2) At noon (LT 12:00)
(3) At midnight (eclipse, LT 0:00)
(4) At exit out of eclipse (LT 0:36)

(1) At LT 6:00 (Fig.4)

As the sunlight incident on the LDR is small, the potential of the body gets negative largely, about –3.7kV. The potential difference between the body and CG on the SAP becomes large apart from the body. Namely, the maximum potential difference is about 1.2kV between CG4 and the body.

However, sunlight casts on the actual LDR because the shape of the LDR is not plate and recessed as seen in Fig.1. Therefore, the potential difference is thought to be much smaller.

(2) At LT 12:00 (Fig.5)

As the photoemission current from LDR is very large, the absolute potential of the body becomes very close to the space plasma potential. And the charge-up of each CG is much low.

(3) At LT 0:00 (Fig.6)

Figure 6(a) shows the time history of the absolute potential after entering in eclipse. And Fig.6(b) shows the potential distribution on the surfaces of ETS-VIII at the time longer than 3,000sec after entering in eclipse. The absolute potential gets saturated in about 2,500sec and the potential of the body is about –9kV. Like the case of (1), dawn, the potential difference on CG4 is the largest among the four CG's on the SAP and the value is about 2.9kV.

(4) LT 0:36 (Fig.7)

In this case, the incident angle of the sunlight is about 9 degree from the +Z axis. Therefore the sunlight fully casts on the LDR and the enough photoemission current from the LDR keeps the potential of the satellite close to 0V.

In orbit, the shadow of the truss of the LDR casts on the SAP at dawn. To simulate this situation, we conducted the analysis of the case which shadow only casts on CG1 of the SAP. Figure 8 shows the time history of the absolute potential in that case. Comparing with Fig.4, the potential on the CG1 becomes close to that of the body. The potential difference between CG1 and CG2 is about 500V. This shows that one string of the solar cells has the possibility to get the potential difference of about 500V to the shadowed string.

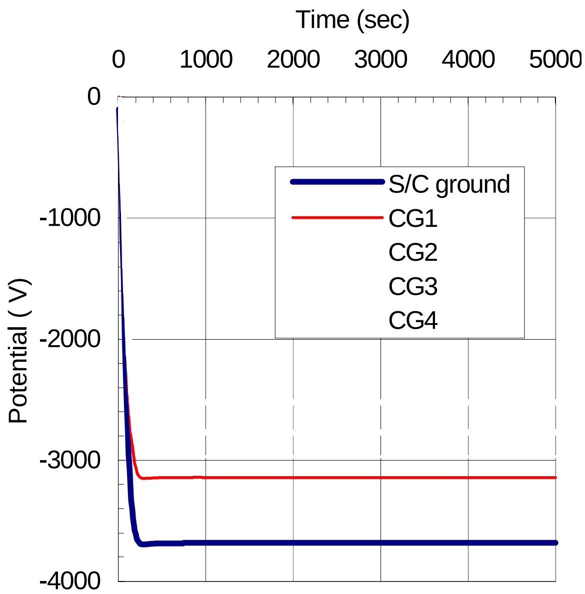


Fig.4 Potentials at LT 6:00

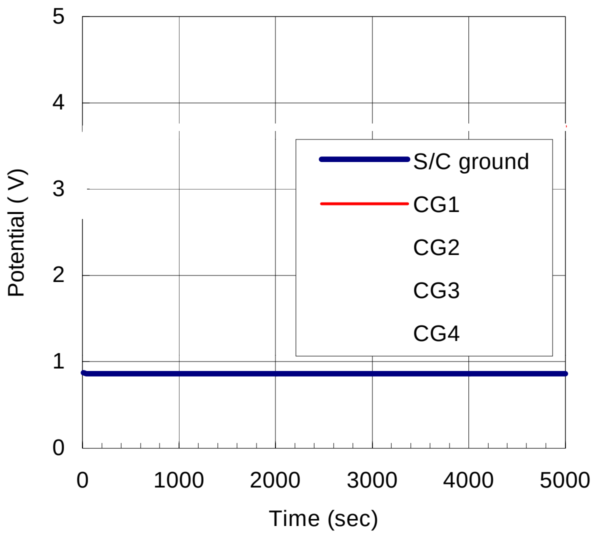
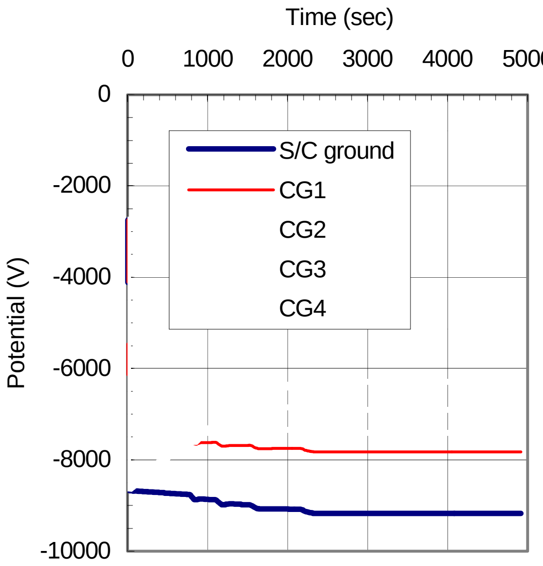
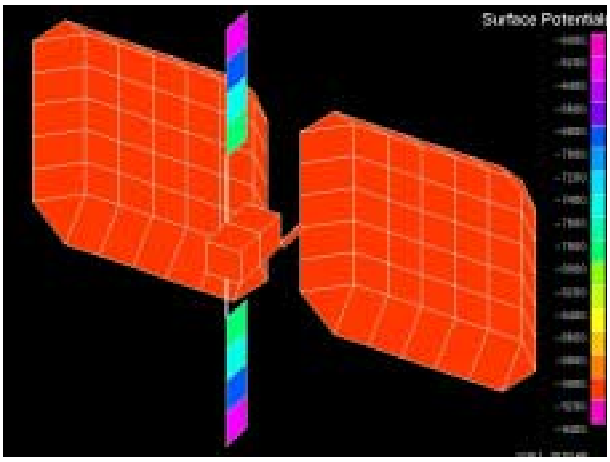


Fig.5 Potentials at LT 12:00



(a) Potentials at LT 0:00



(b) Potential distribution on ETS-VIII at LT 0:00

Fig.6 Potentials at LT 0:00

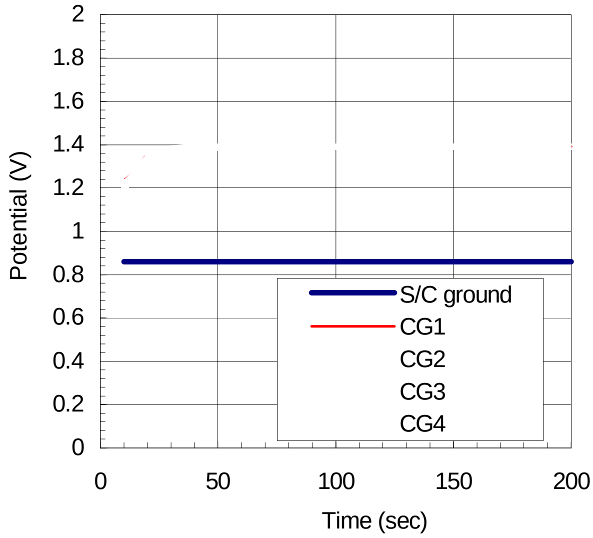


Fig.7 Potentials at LT 0:36

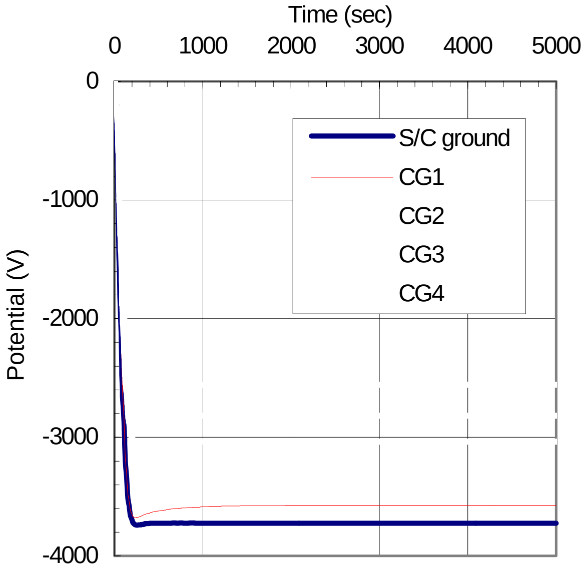


Fig.8 Potentials in case of CG1 in shadow

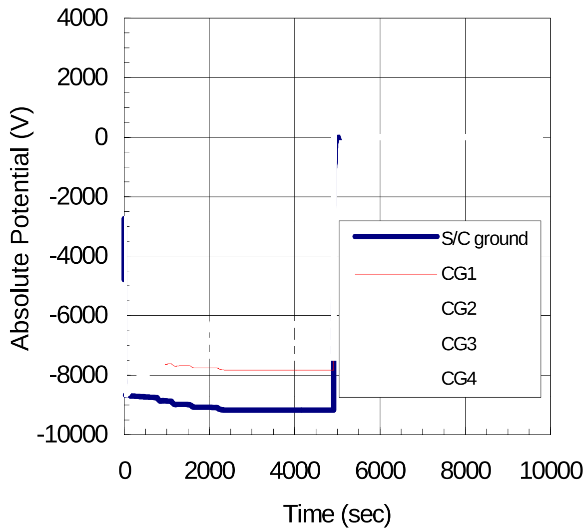
3.3 Transient Analysis

We conducted the transient analysis of ETS-VIII by connecting the quasi-static analysis in eclipse with that at dawn in order to predict the potential change before and after eclipse.

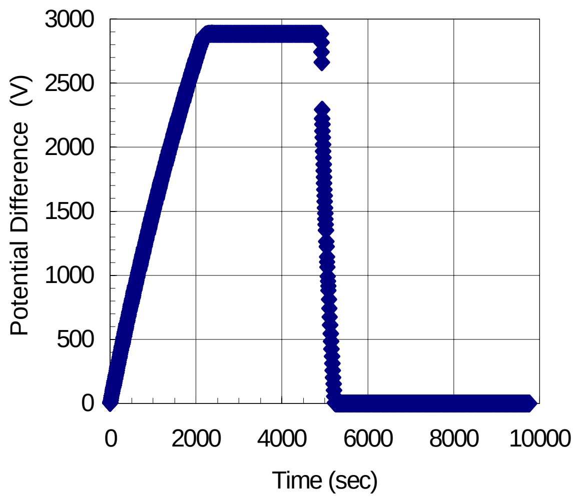
Figure 9(a) shows the time profile of the absolute potential and Fig.9(b) shows the potential difference between the body and the CG4.

In eclipse, the maximum potential difference between the CG4 and the body is about 2.9kV as described above. At the time getting out of the eclipse, the absolute potential of the body drifts to near 0V of the space plasma potential. On the other hand, the absolute potentials of CG's are 2.9kV biased positively to the space plasma at that time. After that, the potentials reached to near 0V due to the effect of photoemission.

From these results, the situation of electrostatic charging on ETS-VIII is illustrated in Fig.10 schematically.

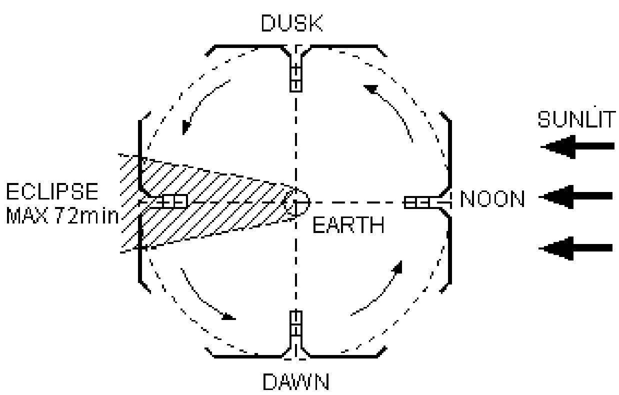


(a) Potentials on the satellite surfaces

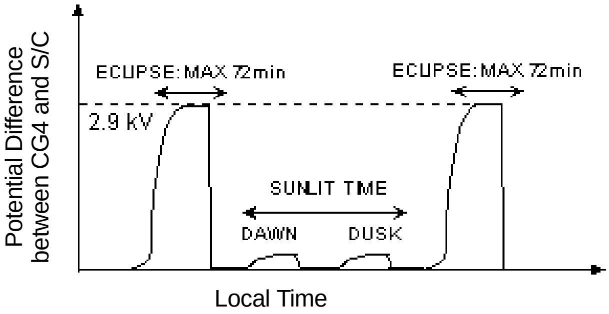


(b) Potential difference between the body and CG4

Fig.9 Potential profile at time getting out of eclipse



(a) ETS-VIII in orbit



(b) Change of potential difference on ETS-VIII

Fig.10 Charging on ETS-VIII

4. DISCUSSION

NASCAP/GEO analyses of satellite have been done by many researchers [2,3]. The results are,

1) In eclipse, the satellite's conductive body gets charged up to large negative potential. And at the time getting out of the eclipse it becomes to near 0V immediately.
2) The potential difference between the cover glass on the solar array panel and the conductive body is the order of kV.

Therefore the results of our NASCAP/GEO analysis are reasonable.

From the analysis, discharge is possible to occur on the SAP in eclipse. In this case, the potential difference of 2.9kV between the surface of the cover glass and the conductive CFRP of the same potential with the conductive body is possible to cause surface discharge along the side surface of the cover glass. As if the discharge occurs, the discharge energy is thought to be small, because the area of one cover glass is much smaller than the area of one CG used in NASCAP/GEO analysis. Therefore the discharge energy is not enough to melt and disconnect silver interconnector of the solar cell. It is also thought to have no energy to puncture Kapton film covering the CFRP substrate. Moreover, as the countermeasure to its possibility, silicone adhesive, RTV, fills between the solar cells of ETS-VIII to prevent triggering discharge.

It is emphasized that arc discharge is caused by the occurrence of the plasma due to triggering discharge on the cover glass in the case of the voltage difference of 100V between the neighboring strings of the cells [2]. In ETS-VIII satellite, the maximum voltage difference between the strings is designed to be lower than 60V, that is, the probability of the discharge is very low [5]. Also as mentioned above, RTV is filled between the cells.

5. CONCLUSION

We carried out the charging analysis of ETS-VIII of Japan by means of NASCAP/GEO in the severe space plasma environment. From this analysis, the followings are obtained.

1) Maximum potential difference of about 2.9kV appeared between the surface of the cover glass of the solar cell and the conductive body of the satellite.
2) Although the potential of 2.9kV is possible to cause discharge, the influence to the satellite is thought to be small.

ACKNOWLEDGEMENT

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