ETS-VIII Solar PDL Plasma Interaction Problem Approach

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Abstract

NASDA(National Space Development agency of Japan) is developing Engineering Test Satellite VIII (ETS-VIII) to establish and verify the large-scale geosynchronous satellite bus technology. ETS-VIII bus employs regulated 100V bus and Xe ion thruster system. Therefore, we conducted several measurements, analysis and ground test, namely Differential-Charge-Experiment and Plasma-Interaction-Experiment, in order to verify the ETS-VIII solar array design for following issues.

- Plasma interaction plumed from ion thruster
- Differential charging caused by sub-storm

The plasma-interaction-experiment showed that the solar array has enough design against the ion-thruster plumed plasma interaction. The differential-charge-test is under verification now.

1. Outline of ETS-VIII

In-orbit image of the ETS-VIII is shown in Figure 1, and Table 1 shows its major characteristic.

<table>
<thead>
<tr>
<th>Table 1. ETS-VIII Major Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
</tr>
<tr>
<td>Launch vehicle</td>
</tr>
<tr>
<td>Launch date</td>
</tr>
<tr>
<td>Launch site</td>
</tr>
<tr>
<td>Orbit</td>
</tr>
<tr>
<td>Station Keeping</td>
</tr>
<tr>
<td>Satellite weight</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Generated electric power</td>
</tr>
</tbody>
</table>

2. Objectives of ETS-VIII

ETS-VIII has the following development objectives:

(1) Technology for 3-ton class spacecraft bus, most advanced in the state of the arts, that can fully supports various missions becoming necessary for the space activities in the outset of the 21-st century.

(2) Technology of Large-scale Deployable Reflector (maximum outer size 19m by 17m), most advanced and largest of its kind.

(3) Mobile satellite communication system technology that can provide an audio/data communication with hand-held terminal.

(4) Mobile satellite multimedia broadcast system technology with compact disk-class high quality sound and data transmission.

(5) Base technology of satellite positioning in use of high stability clock.

3. ETS-VIII Solar Array Design

ETS-VIII solar array employs the following cell and cover glass:

- Solar Cell; High efficiency Si-IBF (Integrated Bypass function)
- Cover glass; BRR/s-0213

ETS-VIII array consists of 88 strings (two wings), each with 262(average) Si-IBF solar cells. Figure 2 shows the basic layout of the strings. While each string produces approximately 130V open circuit, the spacecraft shunt limits the bus to 110V. Each string is laid out as a row of 66 cells, and arranged by four lines. Two strings are connected together in the harness. The gap between adjacent cells is potted with nonconductive adhesive as same as previous NASDA's spacecraft solar arrays design, according to some design guidelines.1,2 Each string produces approximately 1.32A as maximum in the predicted worst conditions, and diodes in spacecraft shunt provide isolation at the two-string level (2.64A).

The ETS-VIII array therefore has adjacent cells with 55V potential difference with a current capability of 2.64A (worst case).

![Figure 2. ETS-VIII String Layout](image)

4. Preparation for validation test

Following measurements and analysis were carried out in order to clarify the both experiments conditions.

(1) Plasma diagnosis in plume of the ion thruster.

   Plasma density (near-field of the thruster) was measured by Langmuir probe in the ground test vacuum chamber.

(2) Numerical analysis of plasma density around the solar array.

   Based on the measured result, numerical analysis was carried out.

(3) Spacecraft charging analysis.

   We used NASCAP/GEO to analyze the spacecraft charging expected on the ETS-VIII.

The above (1) and (2) define plasma density of vacuum chamber for the plasma-interaction-experiment. The above (3) defines bias and differential voltage for the differential-charge-experiment.
5. Plasma Diagnosis and Numerical Analysis

5.1 Plasma Diagnosis
The ion thruster is 12-cm diameter Kaufman type 20mN xenon ion thruster for North-South station keeping of ETS-VIII. The measurement was performed the following two-operation modes and two-distances:
- DISCharge mode; No accelerator grid voltage.
- BEAM mode; beam extract mode.
- Distance; 500mm and 1000mm from the thruster.

The probe was set on a driving mechanism and explored a range of radial and axial positions within the plasma. Figure 3 shows measurement configuration image. Figure 4 shows the results for plasma density determined at two distances from the exit plane. The detail result will be presented in the paper of Ref.[3].

5.2 Numerical Analysis
The nearest solar array from the ion thruster is approximately 5.2m beyond, and there is in the direction of approximately 41 degrees from a center of thrust beam. From the result of plasma diagnosis, low energy plasma density around the ion thruster is between about $4.0 \times 10^{13}/m^3$ and $5.0 \times 10^{13}/m^3$. The plasma density around the solar array was calculated by the particle-in-cell method based on the above-mentioned value. This analysis was carried out by Kyushu Institute of Technology. Figure 5 shows the analytical results of plasma density around the solar array. From the result of analysis, plasma density is approximately $5.0 \times 10^{10}/m^3$ around the nearest solar array.

Therefore, we judged that the condition applied to the plasma-interaction-experiment is enough even by $5 \times 10^{11}/m^3$. 

![Figure 1. ETS-VIII In-orbit Image](image1)

![Figure 3. Measurement configuration image](image3)

![Figure 4. Plasma density at 20mN nominal thrust](image4)

![Figure 5. Plasma density around the solar array](image5)
6. Spacecraft Charging Analysis

The ETS-VIII NASCAP model figure is shown in Figure 6. The major features are the following material.

- **Body**: mostly covered with conducting thermal blankets and Optical Solar Reflector (OSR) with ITO.
- **Solar Array**: surface cover glass and backs of which are also covered with a black conducting polymer.
- **LDR**: surface mesh and it plate molybdenum with gold.

![Figure 6. NASCAP model of the ETS-VIII](image)

The calculations were performed under the condition of the charging environment as shown in Table 2. Subsequently, we performed sensitivity studies. It was showed that spacecraft differential charges result is influenced by especially secondary electron yield due to incident electron of cover glass. The surface of the cover glass is coated by zirconium dioxide (ZrO$_2$). We did not have known its correct value, therefore we measured the SEE (Second Electron Emission) coefficient using a single-pulsed electron beam with a SEM.[6] Figure 7 shows measurement configuration. Primary electrons and secondary emitted electrons were collected by a biased (+40 V) Faraday cup. The ratio of secondary to primary current gives the SEE coefficient.

![Figure 7. SEE measurement SEM](image)

<table>
<thead>
<tr>
<th>Case</th>
<th>Grou nd(V)</th>
<th>CG1 (V)</th>
<th>CG2 (V)</th>
<th>CG3 (V)</th>
<th>CG4 (V)</th>
<th>Max Diff.(V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun; +X</td>
<td>-3684</td>
<td>-3141</td>
<td>-2970</td>
<td>-2769</td>
<td>-2522</td>
<td>1162</td>
</tr>
<tr>
<td>Sun; -Z</td>
<td>0.874</td>
<td>3.453</td>
<td>3.451</td>
<td>3.451</td>
<td>3.453</td>
<td>2.578</td>
</tr>
<tr>
<td>Eclipse</td>
<td>-9150</td>
<td>-7820</td>
<td>-7400</td>
<td>-6920</td>
<td>-6640</td>
<td>2504</td>
</tr>
</tbody>
</table>

![Table 2. Charging Analytical Result Summary](image)

Figure 8 shows typical result of SEE coefficient of BRR/s-0213 cover glass. This work was supported by KEK (High Energy Accelerator Research Organization).

![Figure 8. SEE coefficient of BRR/s-0213](image)

The analytical result that was reflected the above-mentioned SEE coefficient is shown in Table 3, Figure 9 and Figure 10. While we calculated several cases, the detail result will be presented in the paper of Ref.[7]. The NASCAP calculation shows that maximum differential voltage observed at exit of eclipse, which reaches approximately 2.5kV. The NASCAP calculation also shows that ETS-VIII does not charge at local noon and local midnight (eliminate eclipse) in the orbit. The reason is that the photoemission from LDR-Surface prevents charging.

![Figure 9. Sun direction +X case](image)

![Figure 10. Eclipse case](image)
7. Test Condition and Test Configuration

Figure 11 and Figure 12 show the typical test setup. A qualification coupon panel from the array development contract was used for the experiment, which has 3 strings as a row of 5 cells, and other design is the same as the ETS-VIII solar array. ETS-VIII basic experiment conditions are defined as shown in Table 4 based on the analytical results of paragraphs 5 and 6, however the experiment were performed in variety plasma densities and bias voltages by Kyushu Institute of Technology. In the Differential charge experiment, the coupon panel will be charged mainly with the electron gun.

Each experiment cases simulate the following spacecraft condition in the orbit.

Case1; Plasma Interaction Positive Bias Test
This test case simulates North-South station keeping maneuvering using the Ion-thruster.
Under the neutralizer operation of ion-thruster, the solar array has a positive potential with respect to space plasma, where the spacecraft ground is approximately 0V.
The plus-terminals-end of arrays collects electrons. Extreme collection phenomenon (Snap Over) may be caused, and carried out in the plasma with comparatively high density. It causes a lot of electric power loss.

Case2; Plasma Interaction Negative Bias Test
When the neutralizer does not emit sufficient electron or the spacecraft is exposed to dense plasma (i.e. perigee of transfer orbit), the spacecraft ground is biased negative to approximate array voltage (i.e.-110 volts). It causes a trigger arc and sustained arc.

Case3; Ion-thruster Neutralizer failure simulation
During the Ion-thruster beam extract mode operation, if the neutralizer failure is occurring, the satellite ground will be biased rapidly negative (i.e. beam voltage; approximately –1kV).
It causes a trigger arc and sustained arc.

Case4; Worst Case Differential Charge simulation by sub-storm

8. Results
In this paper, we describe the outline of the experiment results. The detail result will be presented in the paper of Ref.[8].

In the case 1, we observed about 0.005mA collection current at 110V. When it is calculated to the whole solar array area, estimated power loss is approximately 1.3W. It is negligible compared with the total generated power. Figure 13 shows the voltage dependency of collection current, where the Snap Over is not observed near 110V. The Snap Over is observed about 220V.

<table>
<thead>
<tr>
<th>Test Case</th>
<th>Va  (V)</th>
<th>Vb  (V)</th>
<th>Vc  (V)</th>
<th>Diff. volts (V)</th>
<th>Plasma Density (m⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma Interaction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case1*</td>
<td>55</td>
<td>55</td>
<td>0</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Case2*</td>
<td>55</td>
<td>55</td>
<td>-110</td>
<td>N/A</td>
<td>Ditto</td>
</tr>
<tr>
<td>Case3**</td>
<td>N/A</td>
<td>55</td>
<td>-500</td>
<td>N/A</td>
<td>Ditto</td>
</tr>
<tr>
<td>Differential Charge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case4</td>
<td>N/A</td>
<td>55</td>
<td>-9k</td>
<td>~2.5k</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*; No capacitance **; 200～400nF

Fig 13. Collection current against bias voltage
In the case 2, we experimented whether trigger arc would occur or not. There was no observation of an arc during 5 hours at 110V negative bias voltage. The experiment time simulated the ion-thruster operation, operated by a unit of 5 hours at Descending-Node and Ascending-Node of the orbit. Figure 14 shows the voltage dependency of arc rate. The arc is observed on the voltage of approximately 250V or more.

![Fig 14. Arc rate against bias voltage](image)

In the case 3, we experimented whether sustained arc would occur or not. In the present experiment, Vc was set to 500 volts negative. The trigger arc was observed within some dozens of seconds, after adding the bias voltage. But there was no observation of sustained arc. Figure 15 shows discharge current of each string. The power supply of ion-thruster has function to detect the neutralizer operation failure. If the failure would occur, beam voltage will be cut off within several milliseconds.

![Fig 15. Discharge current (trigger arc)](image)

The case 4 is under experiment now. In a preliminary test, we consider about a pressure of chamber and additional capacitance.

9. Differential Charge Monitoring in the orbit
ETS-VIII has POtential Monitor (POM) to measure difference potential. POM is mounted on the earth panel of ETS-VIII. Figure 15 and 16 show constitution of POM and conception of POM. Three samples can be mounted on a board and their potentials are output through detected systems respectively. The leaked electric field from an aperture of a sample is modulated by a chopper with 1kHz, and the electrostatic electrode detects the weak electric field. We have plan to selecting the following three cover glasses for the samples of POM, BRR/s-0213, CMX-BRR and CMG-AR. We expect that POM will measure a charging behavior of each sample by ion-thruster operation and sub-storm. The measurement result will be reflected in the design of the next satellite.

![Figure 16. Constitution of POM](image)

![Figure 17. Conception of POM](image)

10. Conclusions
We evaluated that ETS-VIII solar array has enough design against plasma interaction by ion-thruster. The following factors were also effective to solution of the problem.
- ETS-VIII solar array has comparatively long boom and yoke in order to avoid the shadow of LDR. It is effective also to avoid plumed plasma.
- ETS-VIII Kaufman type ion-thruster has comparatively narrow beam profile (e.g. compared with Hall type ion-thruster).

We will perform differential charge experiment as soon as possible, and the results will be presented at next opportunity.

11. Acknowledgements
We would like to many thanks to Dr. Saito and Dr. Michizono (KEK), express for they gave us the opportunity to measurement SEE coefficient of the cover glass.
We would like to express many thank to Dr. Kuninaka (ISAS) for his valuable help in this work.
12. Reference