宇宙機帯電電位評価における最悪環境
Spacecraft charging potential estimation in the worst case environments

豊田和弘、五家健夫

NWI Spacecraft charging potential estimation in the worst case environments

- Background
  - No criteria to estimate worst case of spacecraft charging in each space environment
  - Worst charging potential should be tested in ESD ground testing (ISO-11221)

- Main purpose
  - Provide space plasma environments for worst case differential potential simulation
  - Provide how to estimate worst potential difference with simulation code

Workshop in Tokyo

2013 Jan.

2014 Jan.

ISO draft

- Main purpose
  - Provide space plasma environments for worst case differential potential simulation
    - Round-robin simulation in GEO environment
  - Provide how to estimate worst potential difference with simulation code
- Definition of differential potential
  - Between insulators and spacecraft body
  - Focus on solar panel
- Orbit
  - GEO, PEO, MEO

3

Contents of ISO draft

- **Criteria for worst case environment**
- **Procedures for application to spacecraft design**
- **Space environment for worst case simulation**
  - **GEO worst case environment**
  - **PEO worst case environment**
  - **MEO worst case environment**
- **Annex A (informative) Spacecraft charging analysis tools**
  - **COULOMB-2**
  - **MUSCAT**
  - **NASCAP-2k**
  - **SPIS**
- **Annex B (informative) Space plasma environment**
  - **GEO plasma environment**
  - **PEO plasma environment**
  - **MEO plasma environment**
  - **LEO plasma environment**
- **Annex C (informative) Round-robin simulation**
- **Annex D (normative) Material property**

4

Voting as NI1021

- Title: Spacecraft potential estimation in worst case environment
- By July 25th

5

Voting result

Member responses - Votes by members																	
Country (Member body)	Status*	1a. Agree to add to work programme							Market relevance	1b.Stakeholders consultation		2. Relevant documents		3. Comments		4. Participation	
		Yes				No		Abs									
		20.00	20.20	30.00	40.00	PWI: Yes	PWI: No			Yes	No	Yes	No	Yes	No	Yes	No
Brazil (ABNT)	P	X							X	X			X		X		X
China (SAC)	P	X							X	X			X		X	X	
Finland (SFS)	P							X		X			X		X		X
France (AFNOR)	P							X		X			X		X		X
Germany (DIN)	P							X		X			X		X		X
India (BIS)	P							X							X		X
Italy (UNI)	P	X							X	X			X		X		X
Japan (JISC)	P	X							X	X		X			X	X	
Russian Federation (GOST R)	P	X							X	X			X		X	X	
Ukraine (DTR)	P							X		X			X		X		X
United Kingdom (BSI)	P							X		X			X		X		X
United States (ANSI)	S	X							X	X			X		X	X	
Sub-Total Question 1a		6	0	0	0	0	0	6									
Totals		6				0		6	6	11	0	1	10	0	12	4	8

IS WD 19923

List of experts

- Japan, Mengu Cho, Kyushu Institute of Technology
- China, Weiquan Feng, Beijing Institute of Spacecraft Environment Engineering
- Russia, Lobanov Alexey, TSNIImash
- USA, Dale Ferguson, Space Environment Technologies

MUSCAT and NASCAP-2k

ROUND-ROBIN SIMULATION

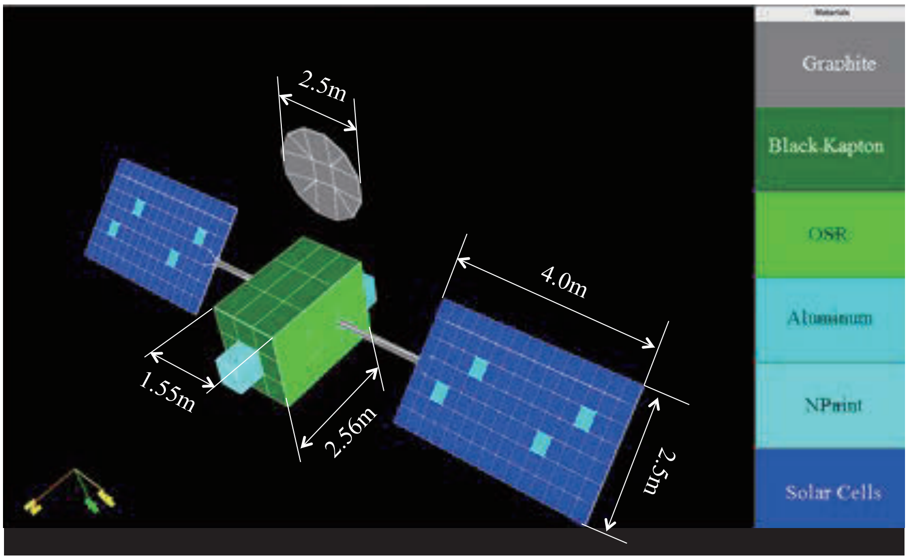
8

Round-robin simulation

- Decide GEO worst-case environment
- MUSCAT, NASCAP-2k, SPIS, COULOMB-2
- Simulation condition
  - Satellite model
    - AFRL proposed model
  - Plasma environment
    - AFRL proposed condition
    - LANL worst

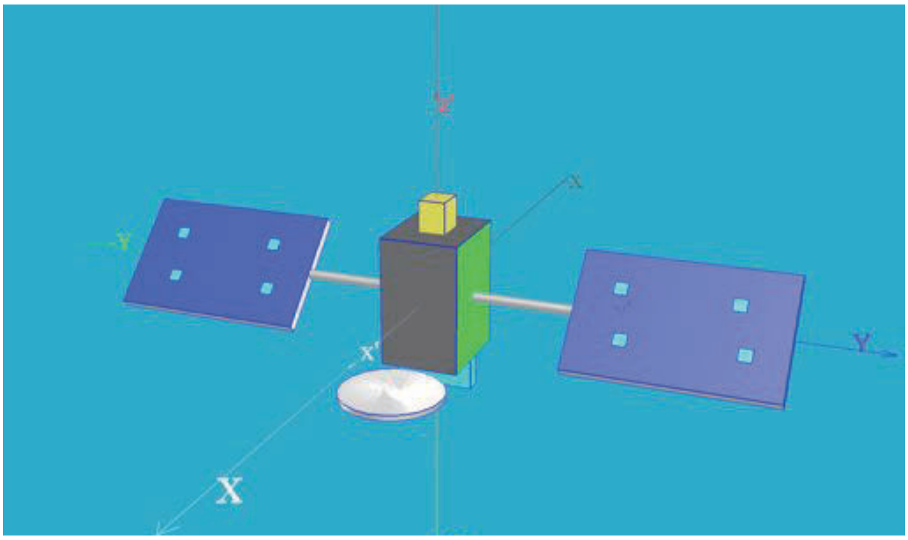
9

Model: NASCAP-2k



10

Model: MUSCAT



11

Material property

Material	Dielectric Constant	Thickness (m)	Bulk Conductivity ($\Omega^{-1}m^{-1}$)	δ_{max}	E_{max} (keV)	Photoemission (A m^{-2})
Graphite	1	1.00E-03	-1	0.93	0.28	7.20E-06
Aluminum	1	1.00E-03	-1	0.97	0.3	4.00E-05
Black Kapton	3.5	2.50E-06	-1	5.2	0.90	5.00E-06
Kapton	3.5	1.27E-04	1.00E-16	2.1	0.15	2.00E-05
Solar Cells (MgF2)	3.8	1.25E-04	1.00E-13	5.8	1	2.00E-05
OSR	4.8	1.50E-04	1.00E-16	3.3	0.5	2.00E-05
NPaint	3.5	1.27E-04	1.00E-16	2.1	0.15	2.00E-05

12

Plasma environment

Environment Name	Ne1	Te1	Ne2	Te2	Ni1	Ti1	Ni2	Ti2
	(m^{-3})	(eV)	(m^{-3})	(eV)	(m^{-3})	(eV)	(m^{-3})	(eV)
SCATHA-Mullen1	2.00E+05	400	2.30E+06	24800	1.60E+05	300	1.30E+06	28200
SCATHA-Mullen2	9.00E+05	600	1.60E+06	25600	1.10E+05	400	1.70E+06	24700
ECSS-E-ST-10-04C (SCATHA 1979)	2.00E+05	400	1.20E+06	27500	6.00E+05	200	1.30E+06	28000
NASA Worst-Case	1.12E+06	12000			2.36E+05	29500		
ATS-6	2.36E+06	29500			2.36E+05	29500		
MIL-STD-1809	2.36E+06	3100	6.25E+05	25100	6.00E+05	200	1.20E+06	28000
Galaxy 15	4.58e+04	55600			1.00E+05	75000		
LANL-KIT	5E+06	13500			2.5E+05	5000		

13

Simulation result of NASCAP-2k

	Daylight charging after 2000 sec					
	Min Chg	Max Chg	Frame	-Frame	Max-Min	Max-Frame
Galaxy15	-802	9.56	2.751	-2.751	811.56	6.81
NASA Worst Case	-9286	-1518	-2415	2415	7768	3940
ATS-6	-13910	-3617	-5779	5779	10293	2162
SCATHA-Mullen1	-11870	-5236	-8468	8468	6634	3232
SCATHA-Mullen2	-10940	-4077	-6573	6573	6863	2496
ECSS-E-ST-10-04C (SCATHA 1979)	-10870	-3512	-5640	5640	7358	2128
MIL-STD-1809	-5728	-1407	-2267	2267	4321	860

14

Simulation result of NASCAP-2k

	Night-time charging after 2000 sec					
	Min Chg	Max Chg	Frame	-Frame	Max-Min	Max-Frame
Galaxy15	-17820	-17410	-17590	17590	410	170
NASA Worst Case	-13230	-5687	-9153	9153	7543	3466
ATS-6	-18310	-9733	-13220	13220	8577	3487
SCATHA-Mullen1	-11980	-6752	-10950	10950	5228	4198
SCATHA-Mullen2	-11160	-6010	-9736	9736	5150	3726
ECSS-E-ST-10-04C (SCATHA 1979)	-11430	-6050	-9521	9521	5380	3471
MIL-STD-1809	-6312	-3393	-5509	5509	2919	2116

15

Simulation result of MUSCAT

Daylight

	Time, s	Min Chg	Max Chg	Abs Chg (frame)	Max-Min	Max-Frame	Min-Frame
NASA Worst Case	2000	-14600	-40	-1820	14600	1780	-12800
ATS-6	2000	-19400	-70	-3400	19300	3330	-16000
SCATHA-Mullen1	1835.5	-41500	-350	-16100	41200	15700	-25400
SCATHA-Mullen2	2038	-34000	-60	-10300	33900	10300	-23700
ECSS-E-ST-10-04C (SCATHA 1979)	2006.6	-28800	-160	-7450	28600	7290	-21400
LANL-KIT	2021.1	-38800	-290	-15000	38500	14800	-23700

16

Simulation result of MUSCAT

Night-Time

	Time, s	Min Chg	Max Chg	Abs Chg (frame)	Max-Min	Max-Frame	Min-Frame
NASA Worst Case	2000	-43700	-42900	-43300	870	402	-468
ATS-6	2000	-63800	-63200	-63500	600	270	-330
SCATHA-Mullen1	2000	-107000	-102000	-105000	5600	3420	-2170
SCATHA-Mullen2	2000	-112000	-107000	-110000	4890	2700	-2190
ECSS-E-ST-10-04C (SCATHA 1979)	2000	-70000	-67100	-68600	2870	1520	-1350
LANL-KIT	2000	-72900	-71800	-72300	1030	468	-566

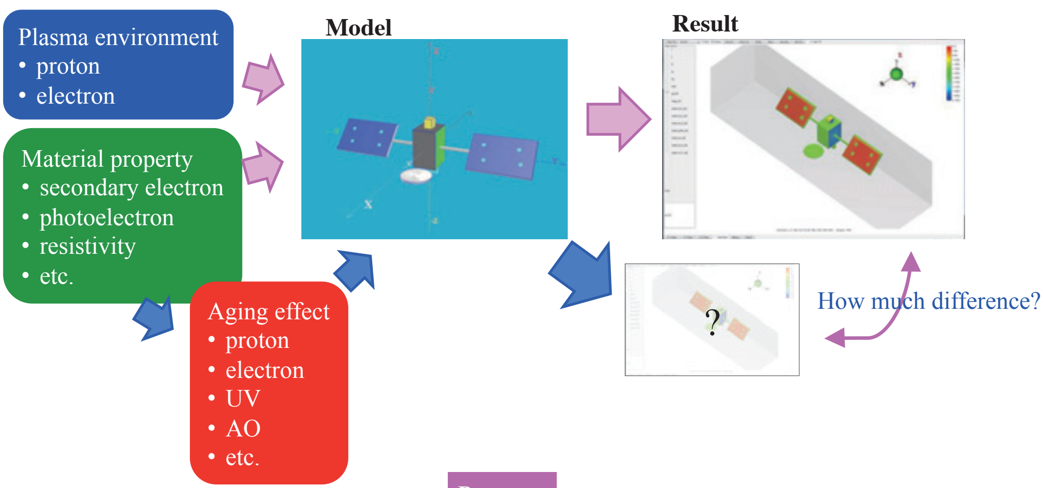
17

Summary of round-robin simulations

- Round-robin simulations were performed with the same simulation model and environments between Nascap-2k and MUSCAT.
- Both types of simulations showed large amounts of charging in all the proposed worst-case environments.
- The SCATHA-Mullen 1 double Maxwellian plasma environment showed the largest maximum inverted gradient potentials in both MUSCAT and Nascap-2k simulations.
- The SCATHA-Mullen 1 can be reliably used as a worst-case environment for spacecraft design and testing.

18

Material property for simulation

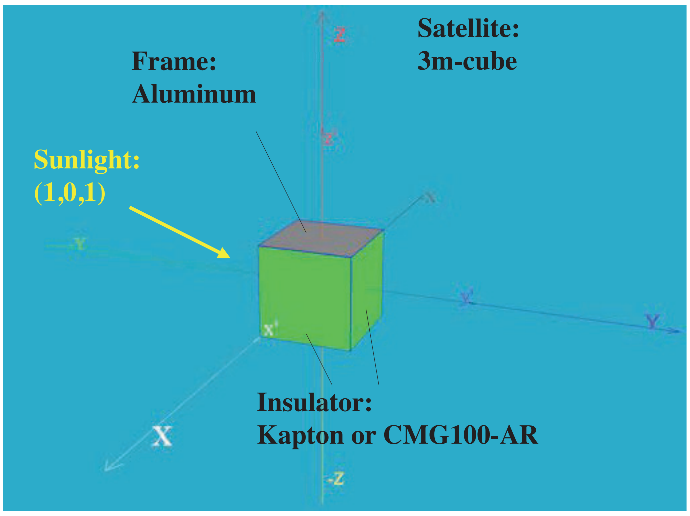


Purpose

Investigate the effect of material property on simulation result

19

Calculation model



Calculation volume: 32 x 32 x 32 Grid: 0.5m

20

Material property

Material	Aging effect	δ_{max}	E_{max} (eV)	Photoemission (A m^{-2})	Bulk Conductivity ($x10^{-14}$ $\Omega^{-1}m^{-1}$)	Dielectric Constant	Thickness (μm)
Aluminum	Nominal	0.97	300	40	-1	1	1000
Kapton	Nominal	1.69	150	3.2	0.7	3.5	25.4
	Proton	1.66	150	7.9	1.6	3.5	25.4
	Electron	1.97	150	3.3	2.9	3.5	25.4
	UV	2.12	150	8.7	0.7	3.5	25.4
	AO	1.1	700	3.0	0.7	3.5	25.4
CMG100-AR	Nominal	6.76	1000	20	1.0	3.8	125
	Proton	2	350	20	1.0	3.8	125
	Electron	6	1000	20	1.0	3.8	125
	UV & Multi	1.8	200	20	1.0	3.8	125

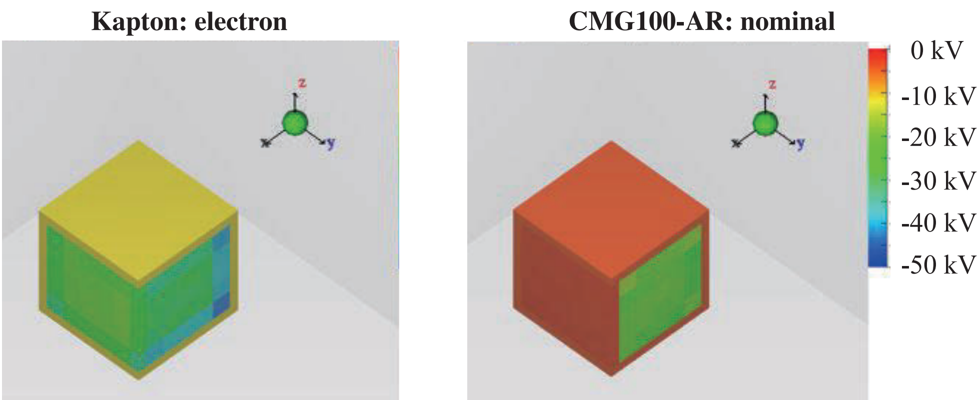
21

Plasma environment

Environment Name	Ne1	Te1	Ne2	Te2	Ni1	Ti1	Ni2	Ti2
	(m^{-3})	(eV)	(m^{-3})	(eV)	(m^{-3})	(eV)	(m^{-3})	(eV)
SCATHA-Mullen1	2.00E+05	400	2.30E+06	24800	1.60E+06	300	1.30E+06	28200

22

Example of calculation results



23

Results

Kapton

Aging	Light side	Dark side	Frame	Light-Frame	Dark-Frame
Nominal	-17300	-19900	-13000	-4300	-6900
Proton	-11900	-23400	-10700	-1100	-12600
Electron	-20400	-29000	-11500	-8900	-17500
UV	-10300	-18200	-10900	600	-7300
AO	-16900	-19500	-13000	-3900	-6500

CMG-100AR

Aging	Light side	Dark side	Frame	Light-Frame	Dark-Frame
Nominal	-1800	-19900	-3000	1200	-16900
Proton	-4000	-29800	-6900	2900	-22900
Electron	-2500	-22800	-4500	1900	-18300
UV	-4000	-30200	-6800	2800	-23500

24

Summary of material property

- The simulations were performed with different material properties by MUSCAT.
- The calculated potentials had a large distribution after aging effect.
- This results will be published on ISO draft (worst case environment for spacecraft charging simulation) for suggestion of considering effect of material properties degradation on spacecraft charging simulation.

25

Schedule

La SEINE

- Workshop in January 26th and 27th 2015
  - Round-robin simulation results
  - ISO draft
- Committee Draft by July 2015