Internal Charging

Joseph I Minow
NASA/MSFC
7th CCMC Workshop
31 March – 4 April 2014
joseph.minow@nasa.gov

ISS image: 7 March 2012
Introduction

## NASA Goddard Space Flight Center, Space Weather Research Center (SWRC)
## Message Type: Space Weather Alert
## Message Issue Date: 2013-07-12T11:35:00Z
## Message ID: 20130712-AL-001

## Summary:

Significantly elevated energetic electron fluxes in the Earth's outer radiation belt. GOES 13 "greater than 0.8 MeV" integral electron flux is above $10^5$ pfu starting at 2013-07-12T11:00Z.

Spacecraft at GEO, MEO and other orbits passing through or in the vicinity of the Earth's outer radiation belt can be impacted.

Activity ID: 2013-07-12T11:00:00-RBE-001.

Outline

- Internal charging
- MeV electron fluence threat thresholds
- NUMIT internal charging model
- Real time GEO internal charging tool
- LEO internal charging tool
Internal (Deep Dielectric) Charging

• High energy (>100 keV) electrons penetrate spacecraft walls and accumulate in dielectrics or isolated conductors

• Threat environment is energetic electrons with sufficient flux to charge circuit boards, cable insulation, and ungrounded metal faster than charge can dissipate

• Accumulating charge density generates electric fields in excess of material breakdown strength resulting in electrostatic discharge

• System impact is material damage, discharge currents inside of spacecraft Faraday cage on or near critical circuitry, and RF noise

PMMA (acrylic) charged by ~2 to 5 MeV electrons
MeV Electron Threat Fluence Thresholds

- NASA-HBK-4002A: ~MeV electron flux $\geq 9 \times 10^4 \text{ e/cm}^2\text{-sec-sr}$
  (10^{10} \text{ e/cm}^2 \text{ in 10 hours})
- CCMC/SWRC: $> 0.8 \text{ MeV electron flux} > 1 \times 10^5 \text{ e/cm}^2\text{-sec-sr}$
- NOAA/SWPC: $> 2 \text{ MeV electron flux} > 1 \times 10^3 \text{ e/cm}^2\text{-sec-sr}$
NUMIT Model for EVA Suit Charging

- NUMIT computes charge deposition, electric field as function of depth in insulating materials due to radiation charging by electrons.
- Five material layers parameterized by electrical resistivity, radiation induced conductivity parameters, dielectric constant.

\[
\nabla \cdot \mathbf{D} = \rho \\
D = \varepsilon E, \quad \varepsilon = \kappa \varepsilon_0 \\
\frac{\partial \rho}{\partial t} = -\nabla \cdot \mathbf{J} \\
\mathbf{J} = J_R + J_C = J_R + \sigma E \\
= J_R + \left[ \sigma_{\text{dark}} + \sigma_{\text{radiation}} \right] E \\
\sigma_{\text{radiation}} = k \left( \frac{dv}{dt} \right)^\alpha, \quad 0.5 < \alpha < 1.0
\]

### Table 1-2 NUMIT Model, Existing Suit

<table>
<thead>
<tr>
<th>Layer</th>
<th>( Z_{\text{eff}} )</th>
<th>( A_{\text{eff}} )</th>
<th>Density (g/cm(^3))</th>
<th>Vol. Resis. (S/m)</th>
<th>( \kappa )</th>
<th>RIC (S/m)</th>
<th>RIC Exp</th>
<th>Depth (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.25</td>
<td>17.19</td>
<td>0.429</td>
<td>1.00E+16</td>
<td>2</td>
<td>1.00E+14</td>
<td>0.7</td>
<td>0.114</td>
</tr>
<tr>
<td>2</td>
<td>5.484</td>
<td>10.008</td>
<td>1.225</td>
<td>1.00E+12</td>
<td>2</td>
<td>1.00E+14</td>
<td>0.7</td>
<td>0.137</td>
</tr>
<tr>
<td>3</td>
<td>6.24</td>
<td>11.99</td>
<td>0.752</td>
<td>1.00E+17</td>
<td>2</td>
<td>1.00E+14</td>
<td>0.7</td>
<td>0.165</td>
</tr>
<tr>
<td>4</td>
<td>6.083</td>
<td>11.291</td>
<td>0.501</td>
<td>1.00E+15</td>
<td>4</td>
<td>1.00E+14</td>
<td>0.7</td>
<td>0.193</td>
</tr>
<tr>
<td>5</td>
<td>5.484</td>
<td>10.008</td>
<td>3.031</td>
<td>1.00E+12</td>
<td>2</td>
<td>1.00E+14</td>
<td>0.7</td>
<td>0.244</td>
</tr>
<tr>
<td>Total</td>
<td>31.541</td>
<td>60.487</td>
<td>5.938</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>6.3082</td>
<td>12.0974</td>
<td>1.1876</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wt Ave</td>
<td>6.0847</td>
<td>11.555</td>
<td>2.0485</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Layer Number | Material
--- | "---
1 | Teflon/Nomex/Kevlar
2 | Neoprene coated Nylon
3 | Dacron polyester
4 | Urethane coated Nylon
5 | Nylon chiffon, Nylon Spandex, water cooling tubes
--- | skin (inside suit)
--- | space (outside of suit)
EVA Suit Study Environment

geo_flux_ts_215.11186.txt → test_env.txt

8 hours   16 hours
Interpolation records for filling data gaps

3/30/2014
Arms and Lower Torso

Current Design*

<table>
<thead>
<tr>
<th>Layer</th>
<th>( \kappa )</th>
<th>( \sigma ) (S/m)</th>
<th>Depth (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.0</td>
<td>( 10^{-16} )</td>
<td>1.14</td>
</tr>
<tr>
<td>2</td>
<td>2.0</td>
<td>( 10^{-12} )</td>
<td>1.37</td>
</tr>
<tr>
<td>3</td>
<td>2.0</td>
<td>( 10^{-17} )</td>
<td>1.65</td>
</tr>
<tr>
<td>4</td>
<td>4.0</td>
<td>( 10^{-15} )</td>
<td>1.93</td>
</tr>
<tr>
<td>5</td>
<td>2.0</td>
<td>( 10^{-12} )</td>
<td>2.44</td>
</tr>
</tbody>
</table>

\( Z_{\text{eff}} = 6 \)

\( A_{\text{eff}} = 12 \)

2.04 g/cm³

\( K_p = 10^{-14} \) S·sec/m·rad

\( \Delta = 0.7 \)

\( \Delta T = 1.0 \) sec

*Using material spec for nylon conductivity

\( \sigma = 10^{-12} \) S/m

geo_flux_ts_215.11186.txt → test_env.txt

3/30/2014
Case 1c

30 mm
0.14 g/cm³
κ=1.13
10⁻¹³ S/m
τ~100 sec

Simulated:
30 days
(720 hours)

Δt=30 sec

LANL-01 2003
geo_flux_ts_1.0017361.txt
30 days
Case 2a

- 60 mm
- 0.14 g/cm³
- $\kappa = 1.13$
- $10^{-19}$ S/m
- $\tau \approx 1157$ days

Simulated:
- 30 days
  (720 hours)
- $\Delta t = 300$ sec

LANL-01 2003
geo_flux_ts_1.0017361.txt
30 days
Electric fields resulting from internal (deep dielectric) charging as function of depth in dielectric material and electrical conductivity. Fields are updated at 5 minute intervals using NOAA GOES >0.8 MeV, >2.0 MeV electron data.

**Geostationary Orbit Internal Charging Tool**

### Time constant for charge decay through conduction: \( \tau = \frac{\kappa \varepsilon_0}{\sigma} \)

<table>
<thead>
<tr>
<th>( \kappa )</th>
<th>( \sigma ) (S/m)</th>
<th>( \tau )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>( 10^{-12} )</td>
<td>( \sim 18 \text{ sec} )</td>
</tr>
<tr>
<td>2</td>
<td>( 10^{-13} )</td>
<td>( \sim 3 \text{ min} )</td>
</tr>
<tr>
<td>2</td>
<td>( 10^{-14} )</td>
<td>( \sim 30 \text{ min} )</td>
</tr>
<tr>
<td>2</td>
<td>( 10^{-15} )</td>
<td>( \sim 5 \text{ hr} )</td>
</tr>
<tr>
<td>2</td>
<td>( 10^{-16} )</td>
<td>( \sim 2 \text{ days} )</td>
</tr>
</tbody>
</table>

---

![GEO Internal Charging Model using GOES-13 e- Flux Data](image)
Geostationary Orbit Internal Charging Tool

GEO Internal Charging Model using GOES-13 e- Flux Data
Data Extracted: 2013 08 26 0000 GMT

GOES Electron Flux (5 minute data)
Geostationary Orbit Internal Charging Tool

GEO Internal Charging Model using GOES-13 e- Flux Data
Data Extracted: 2013 08 26 0900 GMT

GOES Electron Flux (5 minute data)
Begin: 2013 Aug 26 0000 UTC

Updated 2013 Aug 28 23:56:03 UTC
NOAA/SWPC Boulder, CO USA
Geostationary Orbit Internal Charging Tool

GEO Internal Charging Model using GOES-13 e- Flux Data
Data Extracted: 2013 08 26 1800 GMT

GOES Electron Flux (5 minute data)
Begin: 2013 Aug 26 0000 UTC

Updated 2013 Aug 28 23:56:03 UTC
NOAA/SWPC Boulder, CO USA
Geostationary Orbit Internal Charging Tool

GEO Internal Charging Model using GOES-13 e- Flux Data
Data Extracted: 2013 08 27 2100 GMT

GOES Electron Flux (5 minute data)

Updated 2013 Aug 28 23:56:03 UTC
NOAA/SWPC Boulder, CO USA
Geostationary Orbit Internal Charging Tool

GEO Internal Charging Model using GOES-13 e- Flux Data
Data Extracted: 2013 08 28 0600 GMT

GOES Electron Flux (5 minute data)
Begin: 2013 Aug 26 0000 UTC

Updated 2013 Aug 28 23:56:03 UTC
NOAA/SWPC Boulder, CO USA
Geostationary Orbit Internal Charging Tool

GOES Internal Charging Model using GOES-13 e- Flux Data  
Data Extracted: 2013 08 28  1500  GMT

GOES Electron Flux (5 minute data)

Begin: 2013 Aug 26 0000 UTC

Updated 2013 Aug 28 23:56:03 UTC
NOAA/SWPC Boulder, CO USA
Radiation Shielding Option

0.069 g/cm² Al shielding (0.256 mm)  no shielding
Input Data Options

GOES Electron Flux (5 minute data) Begin: 2011 Jun 18 0000 UTC

Updated 2011 Jun 20 17:36:02 UTC

NOAA/SWPC Boulder, CO USA

Fok Radiation Belt Model
[iswa.ccmc.gsfc.nasa.gov]

06/18/2011 Time = 12:00:00 UT En = 425 keV
solid line: Fok-RB boundary

0.425 MeV

2.00 MeV
LEO Internal Charging Model

- 1-D internal charging simulation treating electron flux responsible for charging dielectric materials (or isolated conductors) covered by thin shielding (e.g., MLI):

\[ \kappa \varepsilon_0 \frac{dE}{dt} + \sigma E = J_p \]

where \( J_p \) is the integral electron current density penetrating the MLI shielding, \( \kappa \) is the dielectric constant, \( \varepsilon_0 \) the permittivity of free space, and \( \sigma \) the electrical conductivity of the dielectric material.

- Compute electric field \( E \) and potential \( \Phi \) as function of time using electron flux measurements from NOAA-19 for the incident electron current density, \( J_p \).

- Conductivity \( \sigma \) due only to “dark” conductivity, neglect radiation induced conductivity:
  - Charge loss process due to conduction to ground slows charge accumulation rate and limits ESD events in lower flux environments.
  - Charge, electric field will establishes an equilibrium \( E \sim J/\sigma \) if charging time constant \( \tau = \kappa \varepsilon_0 / \sigma \) for charge loss through conduction is short compared to exposure time.
  - Finite amount of time required for charge to decay through conduction after exposure to electrons.

- Electric field enhancement factor included to account for sharp edges.
Simulated: 0 discharges
Inf days/event
NOAA-19: pi*(90deg + 90deg)
Model 2, \( \tau = 40.97 \) days

\[ J_e(>150.0 \text{ keV}) - J_e(>300.0 \text{ keV}) \text{ electrons} \]

\[ 10.000 \text{ cm} \times 3.000 \text{ cm} \times 0.200 \text{ mm} \]
\( k = 4.00 \)
Dielectric strength = \( 2.50 \times 10^7 \) V/m
0.10 < fract. discharged < 0.30
1.0x field enhancement
1.00e+17 ohm-m

Flux \#/cm²-sec-sr

Electric Field (V/m)

10¹⁴
10¹²
10¹⁰
10⁸
10⁶
10⁴
10²

2011.8 2012.0 2012.2 2012.4 2012.6 2012.8 2013.0
Time (UT)
**LEO Internal Charging Model**

**$J_e(>150.0 \text{ keV}) - J_e(>300.0 \text{ keV})$ electrons**

- Simulated: 65 discharges
- 6.6 days/event
- NOAA-19: $\pi (0\text{deg} + 90\text{deg})$
- Model 2, $\tau = 409.72$ days

**Dimensions:**
- $10,000 \text{ cm} \times 3,000 \text{ cm} \times 0.200 \text{ mm}$
- $k = 4.00$

**Dielectric strength:**
- $2.50 \times 10^7 \text{ V/m}$
- $0.10 < \text{frac. discharged} < 0.30$
- $10.0 \times \text{field enhancement}$
- $1.00 \times 10^{18} \text{ ohm-m}$

**Graph Details:**
- Flux #/cm$^2$-sec-sr
- Time (UT): 2011.8 to 2013.0
- Electric Field (V/m): $10^{6}$ to $10^{14}$
**LEO Internal Charging Model**

Dimensions (LxWxD): 10.000 cm x 3.000 cm x 0.200 mm

Volume resistivity: 1.000e+018 ohm-m

Kappa: 4.0000

Dielectric strength: 2.500e+007 V/m

Efield enhancement: 10.0x

Capacitance: 5.310e-010 Farads

Conduction time constant: 409.7222 days

Fraction (f) discharged: 0.100 < f < 0.300

NOAA-19 electrons: \( \pi \cdot (0^\circ + 90^\circ) \)

Electron energy: 150.0000 keV – 300.0000 keV

<table>
<thead>
<tr>
<th>Arc</th>
<th>Decimal</th>
<th>Day of Year(UT)</th>
<th>Year(UT)</th>
<th>Fraction Discharged</th>
<th>Surface Voltage (Volts) Before and After Arc</th>
<th>Arc Energy (mJoule)</th>
<th>0.10 us</th>
<th>1.00 us</th>
<th>10.00 us</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2012.0710</td>
<td>26.9785</td>
<td>0.2283</td>
<td>500.0</td>
<td>385.9</td>
<td>0.0268</td>
<td>6.06e-001</td>
<td>6.06e-002</td>
<td>6.06e-003</td>
</tr>
<tr>
<td>1</td>
<td>2012.1039</td>
<td>39.0314</td>
<td>0.2004</td>
<td>500.0</td>
<td>399.8</td>
<td>0.0239</td>
<td>5.32e-001</td>
<td>5.32e-002</td>
<td>5.32e-003</td>
</tr>
<tr>
<td>2</td>
<td>2012.1290</td>
<td>48.2109</td>
<td>0.2537</td>
<td>500.0</td>
<td>373.2</td>
<td>0.0294</td>
<td>6.73e-001</td>
<td>6.73e-002</td>
<td>6.73e-003</td>
</tr>
<tr>
<td>3</td>
<td>2012.1399</td>
<td>52.2185</td>
<td>0.2410</td>
<td>500.0</td>
<td>379.5</td>
<td>0.0281</td>
<td>6.40e-001</td>
<td>6.40e-002</td>
<td>6.40e-003</td>
</tr>
<tr>
<td>4</td>
<td>2012.1837</td>
<td>68.2398</td>
<td>0.2647</td>
<td>500.1</td>
<td>367.7</td>
<td>0.0305</td>
<td>7.03e-001</td>
<td>7.03e-002</td>
<td>7.03e-003</td>
</tr>
<tr>
<td>5</td>
<td>2012.1874</td>
<td>69.5824</td>
<td>0.1438</td>
<td>500.6</td>
<td>428.6</td>
<td>0.0178</td>
<td>3.82e-001</td>
<td>3.82e-002</td>
<td>3.82e-003</td>
</tr>
<tr>
<td>6</td>
<td>2012.1891</td>
<td>70.2203</td>
<td>0.1002</td>
<td>500.0</td>
<td>449.9</td>
<td>0.0126</td>
<td>2.66e-001</td>
<td>2.66e-002</td>
<td>2.66e-003</td>
</tr>
<tr>
<td>7</td>
<td>2012.1909</td>
<td>70.8707</td>
<td>0.1937</td>
<td>500.1</td>
<td>403.3</td>
<td>0.0232</td>
<td>5.14e-001</td>
<td>5.14e-002</td>
<td>5.14e-003</td>
</tr>
<tr>
<td>8</td>
<td>2012.1942</td>
<td>72.0668</td>
<td>0.1379</td>
<td>500.0</td>
<td>431.1</td>
<td>0.0170</td>
<td>3.66e-001</td>
<td>3.66e-002</td>
<td>3.66e-003</td>
</tr>
<tr>
<td>9</td>
<td>2012.1965</td>
<td>72.9144</td>
<td>0.1782</td>
<td>500.0</td>
<td>410.9</td>
<td>0.0215</td>
<td>4.73e-001</td>
<td>4.73e-002</td>
<td>4.73e-003</td>
</tr>
<tr>
<td>10</td>
<td>2012.2000</td>
<td>74.1920</td>
<td>0.2192</td>
<td>500.0</td>
<td>390.4</td>
<td>0.0259</td>
<td>5.82e-001</td>
<td>5.82e-002</td>
<td>5.82e-003</td>
</tr>
</tbody>
</table>
Questions?