Internal Charging

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**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 MeV electron flux > \( 1 \times 10^5 \, \text{e/cm}^2\text{-sec-sr} \)
- NOAA/SWPC: > 2 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.

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

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/cm³)</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>1.050</td>
<td>9.79</td>
<td>1.00E+16</td>
<td>1.00E+14</td>
<td>2</td>
<td>1.00E+14</td>
<td>0.7</td>
<td>0.114</td>
</tr>
<tr>
<td>2</td>
<td>0.948</td>
<td>10.00</td>
<td>5.00E+13</td>
<td>1.00E+14</td>
<td>2</td>
<td>1.00E+14</td>
<td>0.7</td>
<td>0.137</td>
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<tr>
<td>3</td>
<td>0.783</td>
<td>12.56</td>
<td>2.00E+13</td>
<td>1.00E+14</td>
<td>4</td>
<td>1.00E+14</td>
<td>0.7</td>
<td>0.165</td>
</tr>
<tr>
<td>4</td>
<td>0.623</td>
<td>11.99</td>
<td>1.00E+15</td>
<td>1.00E+14</td>
<td>2</td>
<td>1.00E+14</td>
<td>0.7</td>
<td>0.193</td>
</tr>
<tr>
<td>5</td>
<td>0.542</td>
<td>10.00</td>
<td>3.00E+13</td>
<td>1.00E+14</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
--- |------------------
--- | space (outside of suit)
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)

3/30/2014
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
### 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/cm$^3$

$K_p = 10^{-14}$ 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
Arms and Lower Torso

![Graph showing E-field magnitude and charge density over time.](image)
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
κ=1.13
10⁻¹⁹ S/m
τ~1157 days

Simulated:
30 days
(720 hours)

Δt=300 sec
Time constant for charge decay through conduction: $\tau = \kappa \varepsilon_0 / \sigma$

<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>~18 sec</td>
</tr>
<tr>
<td>2</td>
<td>$10^{-13}$</td>
<td>~3 min</td>
</tr>
<tr>
<td>2</td>
<td>$10^{-14}$</td>
<td>~30 min</td>
</tr>
<tr>
<td>2</td>
<td>$10^{-15}$</td>
<td>~5 hr</td>
</tr>
<tr>
<td>2</td>
<td>$10^{-16}$</td>
<td>~2 days</td>
</tr>
</tbody>
</table>

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

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 27 1200 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)
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 28 0600 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 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
Geostationary Orbit Internal Charging Tool

GEO Internal Charging Model using GOES-13 e- Flux Data
Data Extracted: 2013 08 29 0000 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**

GEO Internal Charging Model using GOES-13 e⁻ Flux Data
Data Extracted: 2013 07 13 0510 GMT
• 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.
LEO Internal Charging Model

J_e(> 150.0 keV) - J_e(> 300.0 keV) electrons

- Simulated: 0 discharges
- Inf days/event
- NOAA-19: pi*(0deg + 90deg)
- Model 2, tau = 40.97 days

10,000 cm x 3,000 cm x 0.200 mm
k = 4.00

Dielectric strength = 2.50e+007 V/m
0.10 < fract. discharged < 0.30
1.0x field enhancement
1.00e+017 ohm-m

Flux #/cm²-sec-sr

Electric Field (V/m)

Time (UT)

2011.8 2012.0 2012.2 2012.4 2012.6 2012.8 2013.0
LEO Internal Charging Model

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

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

10,000 cm \times 3,000 cm \times 0.200 mm
\( k = 4.00 \)

Dielectric strength = 2.50e+007 V/m
0.10 < fract. discharged < 0.30
10.0x field enhancement
1.00e+18 ohm-m

Flux \#/cm²-sec-sr

2011.8 2012.0 2012.2 2012.4 2012.6 2012.8 2013.0

Time (UT)

Electric Field (V/m)
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: \( \pi \times (0\deg + 90\deg) \)
Electron energy: 150.0000 keV - 300.0000 keV

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