Internal Charging

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7th CCMC Workshop
31 March – 4 April 2014
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## 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 threat fluence 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 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, phantom commands, RF noise, and catastrophic damage to critical electronic components

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

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

[Diagram showing flux levels and thresholds]  

[NASA-HDBK-4002a, 2011]
NUMIT Model for EVA Suit Charging

NUMIT (for “numerical iteration”) estimates charge deposition, electric field as function of depth in insulating materials due to radiation charging by energetic electrons.

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

**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. Resist. (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>
</tbody>
</table>

Total

Average 6.3082 12.0974 1.1876
Wt Ave 6.0847 11.555 2.0485

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)
geo_flux_ts_215.11186.txt → test_env.txt

8 hours  16 hours
Interpolation records for filling data gaps
<table>
<thead>
<tr>
<th>Layer</th>
<th>κ</th>
<th>σ (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>

\[ Z_{\text{eff}} = 6 \]
\[ A_{\text{eff}} = 12 \]
\[ 2.04 \text{ g/cm}^3 \]
\[ K_p = 10^{-14} \text{ S-sec/m-rad} \]
\[ \Delta = 0.7 \]
\[ \Delta T = 1.0 \text{ sec} \]

*Using material spec for nylon conductivity
\[ \sigma = 10^{-12} \text{ S/m} \]

geo_flux_ts_215.11186.txt → test_env.txt
30 mm
1.14 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

GEO, 30 days, High Conductivity
60 mm
1.14 g/cm³
κ=1.13
10⁻¹⁹ S/m
τ~1157 days

Simulated:
30 days
(720 hours)

Δt=300 sec

LANL-01 2003
geo_flux_ts_1.0017361.txt
30 days
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 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
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 1200 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 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)
Begin: 2013 Aug 26 0000 UTC

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

Depth (cm)
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
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 = 0.425 MeV
solid line: Fok-RB boundary

06/18/2011 Time = 12:00:00 UT En = 2.00 MeV
solid line: Fok-RB boundary

Model at CCMC: Fok-RB

Updated 2011 Jun 20 17:36:02 UTC

NOAA/SWPC Boulder, CO USA
LEO Internal Charging Model

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

Simulated: 0 discharges
Inf days/event
NOAA-19: phi(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 #/cm$^2$.sec-str

Electric Field (V/m)

2011.8 2012.0 2012.2 2012.4 2012.6 2012.8 2013.0

Time (UT)
LEO Internal Charging Model

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

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

10.0 cm \times 3.00 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+018 ohm-m

Flux \#/cm^2-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

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: π*(0deg + 90deg)
Electron energy: 150.0000 keV – 300.0000 keV

<table>
<thead>
<tr>
<th>Arc</th>
<th>Decimal Year (UT)</th>
<th>Day of Year (UT)</th>
<th>Fraction Discharged</th>
<th>Surface Voltage (Vols)</th>
<th>Arc Energy (mJoule)</th>
<th>Arc Current (Amp) Before and After Arc 0.10 us 1.00 us 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 6.06e-001 6.06e-002 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 5.32e-001 5.32e-002 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 6.73e-001 6.73e-002 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 6.40e-001 6.40e-002 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 7.03e-001 7.03e-002 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 3.82e-001 3.82e-002 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 2.66e-001 2.66e-002 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 5.14e-001 5.14e-002 5.14e-003</td>
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<tr>
<td>8</td>
<td>2012.1942</td>
<td>72.0668</td>
<td>0.1379</td>
<td>500.0</td>
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</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>
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</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 5.82e-001 5.82e-002 5.82e-003</td>
</tr>
</tbody>
</table>
Collaboration with CCMC

• MSFC represents a user community utilizing CCMC products in our space environment and effects support for NASA programs

• MSFC will provide GEO internal charging code to CCMC

• CCMC will run the code in real-time using both GOES and RBE model data and provide results via iSWA

• Additional MSFC space environment effects codes, data can be provided to CCMC in the future once they have been sufficiently validated including
  – LEO real time internal charging
  – GEO, LEO surface charging
  – GEO single event upset
  – Solar energetic particle acceleration
  – F2-region Ne, Te along ISS orbit (51.6 km, ~400 km)