Internal Charging

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7th CCMC Workshop
31 March – 4 April 2014
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ISS image: 7 March 2012
## 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 $\geq 9 \times 10^4$ e/cm$^2$-sec-sr (10$^{10}$ e/cm$^2$ in 10 hours)
- CCMC/SWRC: > 0.8 MeV electron flux $> 1 \times 10^5$ e/cm$^2$-sec-sr
- NOAA/SWPC: > 2 MeV electron flux $> 1 \times 10^3$ e/cm$^2$-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

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

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>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>
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<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>
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<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>

<table>
<thead>
<tr>
<th>Layer Number</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>---</td>
<td>space (outside of suit)</td>
</tr>
<tr>
<td>1</td>
<td>Teflon/Nomex/Kevlar</td>
</tr>
<tr>
<td>2</td>
<td>Neoprene coated Nylon</td>
</tr>
<tr>
<td>3</td>
<td>Dacron polyester</td>
</tr>
<tr>
<td>4</td>
<td>Urethane coated Nylon</td>
</tr>
<tr>
<td>5</td>
<td>Nylon chiffon, Nylon Spandex, water cooling tubes</td>
</tr>
<tr>
<td>---</td>
<td>skin (inside suit)</td>
</tr>
</tbody>
</table>

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
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>
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<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

$Kp = 10^{-14}$ 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

E-Field Magnitude

Charge Density

$\log_{10}$ Flux

$\log_{10}$ E

$\log_{10}$ E [V/m]

Time (hour)

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
60 mm
0.14 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
Geostationary Orbit Internal Charging Tool

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>( \approx 18 ) sec</td>
</tr>
<tr>
<td>2</td>
<td>( 10^{-13} )</td>
<td>( \approx 3 ) min</td>
</tr>
<tr>
<td>2</td>
<td>( 10^{-14} )</td>
<td>( \approx 30 ) min</td>
</tr>
<tr>
<td>2</td>
<td>( 10^{-15} )</td>
<td>( \approx 5 ) hr</td>
</tr>
<tr>
<td>2</td>
<td>( 10^{-16} )</td>
<td>( \approx 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

Particles cm⁻² s⁻¹ sr⁻¹

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)
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 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

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

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 = 423 keV
solid line: Fok-RB boundary

0.425 MeV

2.00 MeV

3/30/2014
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.
LEO Internal Charging Model

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

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

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)
**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*(0deg + 90deg)
Model 2, tau = 409.72 days

$10.000 \text{ cm} \times 3.000 \text{ cm} \times 0.200 \text{ mm}$
$k = 4.00$

Dielectric strength = $2.50e+007 \text{ V/m}$
$0.10 < \text{fract. discharged} < 0.30$
10.0x field enhancement
$1.00e+18 \text{ ohm-m}$
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: \( \pi \times (0\text{deg} + 90\text{deg}) \)
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 (Volts)</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>
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<td>373.2</td>
<td>0.0294 6.73e-001 6.73e-002 6.73e-003</td>
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<tr>
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<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>
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<td>70.2203</td>
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<td>449.9</td>
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<td>9</td>
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<td>500.0</td>
<td>390.4</td>
<td>0.0259 5.82e-001 5.82e-002 5.82e-003</td>
</tr>
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Questions?