Internal Charging

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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 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 \( \geq 9 \times 10^4 \text{ e/cm}^2\text{-sec-sr} \) 
  (\(10^{10} \text{ e/cm}^2\) 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 \( > 1 \times 10^3 \text{ e/cm}^2\text{-sec-sr} \)
NUMITModel 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

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

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/cm(^3))</th>
<th>Vol. Resis. (S/m)</th>
<th>k</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>
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<tr>
<td>2</td>
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<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>
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<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>
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<tr>
<td>4</td>
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<td>11.291</td>
<td>0.501</td>
<td>1.00E+15</td>
<td>4</td>
<td>1.00E+14</td>
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<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>
</tr>
</tbody>
</table>

Total | 31.541 | 60.487 | 5.938
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)
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>
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<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>
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<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$^3$
$Kp = 10^{-14}$ S-sec/m-rad
$\Delta = 0.7$
$\Delta T = 1.0$ sec

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

gemo_flux_ts_215.11186.txt $\rightarrow$ test_env.txt

3/30/2014
Arms and Lower Torso

E-Field Magnitude

Charge Density

$\log_{10} \text{Flux} \quad [\#/\text{cm}^2\cdot\text{s}]$

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

Time (hour)

0.15 MeV
0.55 MeV
1.10 MeV
5.00 MeV
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

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>(~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 0300 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
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

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

0.425 MeV

2.00 MeV

Updated 2011 Jun 20 17:36:02 UTC
NOAA/SWPC Boulder, CO USA
• 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

$J_e(> 150.0 \text{ keV}) - J_e(> 300.0 \text{ keV})$ 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 = $2.50e+007 \text{ V/m}$
0.10 < fract. discharged < 0.30
1.0x field enhancement
1.00e+017 ohm-m
Simulated: 65 discharges
6.6 days/event
NOAA-19: π*(0deg + 90deg)
Model 2, \(\tau = 409.72\) days

Dielectric strength = 2.50 \times 10^7 \text{ V/m}

0.10 < \text{frac. discharged} < 0.30

10.0x field enhancement
1.00 \times 10^{18} \text{ ohm-m}

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

Flux #/cm²-sec-sr

Electric Field (V/m)

Time (UT)
## 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:** $\pi(0\text{deg} + 90\text{deg})$  
**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)</th>
<th>Arc Energy (mJoule)</th>
<th>Arc Current (Amp) Before and After Arc</th>
<th>Arc Current (Amp) 0.10 us</th>
<th>Arc Current (Amp) 1.00 us</th>
<th>Arc Current (Amp) 10.00 us</th>
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<tr>
<td>0</td>
<td>2012.0710</td>
<td>26.9785</td>
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<td>385.9</td>
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Questions?