Internal Charging

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NASA/MSFC
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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.

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### Outline

- Internal charging
- MeV electron fluence threat thresholds
- NUMIT internal charging model
- Real time GEO internal charging tool
- LEO internal charging tool
• 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

![Diagram of EVA Suit Charging](image)

Table 1-2 NUMIT Model, Existing Suit

<table>
<thead>
<tr>
<th>Layer</th>
<th>$Z_{eff}$</th>
<th>$A_{eff}$</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>
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<tr>
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<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>
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<td>1.00E+14</td>
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<td>11.291</td>
<td>0.501</td>
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<td></td>
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<td>12.0974</td>
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<td></td>
<td></td>
<td>1.1876</td>
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<td>Wt Ave</td>
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<td>11.555</td>
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<td></td>
<td>2.0485</td>
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</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)
EVA Suit Study Environment

LANL/GEO: LANL-01A

2003lan01_5min.sav

0.050-0.075 MeV
0.075-0.105 MeV
0.105-0.150 MeV
0.150-0.225 MeV
0.225-0.315 MeV
0.315-0.500 MeV
0.500-0.750 MeV
0.750-1.1 MeV
1.1-1.5 MeV
0.7-1.8 MeV
1.8-2.2 MeV
2.2-2.7 MeV
2.7-3.5 MeV
3.5-4.5 MeV
4.5-6.0 MeV
6.0-7.8 MeV
7.8-10.8 MeV
10.8-25.8 MeV

$e^{-}/cm^{2}-sec-sr-MeV$

Day of Year

3/30/2014
EVA Suit Study Environment

draw_flux_ts_215.11186.txt → test_env.txt

LANL/GEO: LANL-01A

2003lan01_5min.sav

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>
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<td>$10^{-12}$</td>
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<tr>
<td>5</td>
<td>2.0</td>
<td>$10^{-12}$</td>
<td>2.44</td>
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</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

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

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 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)

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
Radiation Shielding Option

0.069 g/cm² Al shielding
(0.256 mm)
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]

08/18/2011 Time = 12:00:00 UT En = 425 keV
solid line: Fok-RB boundary

0.425 MeV
2.00 MeV

Radiation Belt Model

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

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

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

10.000 cm $\times$ 3.000 cm $\times$ 0.200 mm
$k = 4.00$
Dielectric strength = $2.50 \times 10^7$ V/m
$0.10 < \text{frac. discharged} < 0.30$
1.0x field enhancement
$1.00 \times 10^7$ ohm-m
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, \( \tau = 409.72 \text{ days} \)

- \( 10,000 \text{ cm} \times 3,000 \text{ cm} \times 0.200 \text{ mm} \)
- \( k = 4.00 \)
- Dielectric strength = \( 2.50 \times 10^{-7} \text{ V/m} \)
- \( 0.10 < \text{frac. discharged} < 0.30 \)
- 10.0x field enhancement
- 1.00e+18 ohm-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:  \( \pi \times (0 \text{deg} + 90 \text{deg}) \)

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) 0.10 us</th>
<th>Arc Current (Amp) 1.00 us</th>
<th>Arc Current (Amp) 10.00 us</th>
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<td>385.9</td>
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Questions?