Internal ESD Review

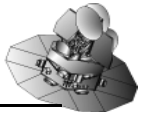
September 9, 1999
Aerospace Corporation
9:00 am - 5:00

Agenda

Topic	Presenter	Time
• Introduction & Objective	All	9:00
• Background	MAP/Aerospace	
– IESD, SCATHA, CRRES, Ground Testing		
– Configuration of other S/C		
• Mission Requirement	MAP	
• Environment	Aerospace	
– MAP Orbit, L Levels, Integrated Flux, CRRES AE8 compare		
• Shielding Analysis	Aerospace	
– Cable analysis		
– Flux behind Thermal Blanket and 7.8 mil Cu		
• Lunch		12:00
• Dielectric and Floating Conductor Charging	MAP/Aerospace	
– Dielectrics Inventory		
– Floating Conductor Inventory		
• Discharge Threat	MAP	
– Interface Circuit Summary		
• Mitigation Plan	MAP	
– Grounding		
– Shielding Plan		
– Filtering		

Objective

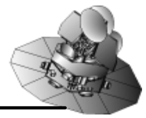
- Assess the adequacy of the MAP Internal ESD mitigation approach
- Review the analysis that supports the implementation approach
- Identify the residual risks with the proposed IESD mitigation approach



Background

- IESD Summary
  - Basics - where ever electrons stop they deposit their charge. Material thickness and density defines the stopping power. As electrons accumulate faster than they bleed off a voltage builds up. If the voltage exceeds the dielectric breakdown limit a discharge or "Lightning Strike" occurs. This discharge can result in a direct hit to a nearby victim or can result in radiated emission that can be picked up by a nearby victim or a victim further away. Concern is damage or upset. Damage can be heat/energy related or electric field related for oxides in small feature size FETs.
  - NASA Handbook "NASA-HDBK-4002 Avoiding Problems Caused by Spacecraft On-Orbit Internal Charging Effects" recommends:

1. <u>Environment</u>
   - $<10^{10}$ electrons /cm^2 over 10 hours
   - Flux <0.1 pA /cm^2
   - AE8 with approx factor of 10 for worst case
2. <u>Shielding</u>
   - >110 mil Al GEOsafe level
   - <0.1 pA/cm^2 Mil Class 1 ESD protection
   - >0.1 and <0.3 pA/cm^2 Mil Class 2 protection
3. <u>Charge Buildup</u>
   - Requirement $<10^{12}$ Ohm cm bulk resistivity (none available)
4. <u>Survive Discharge Energy or Filter to Protect Victim</u>
   - For unknown ESD source - analyze victim with 5000V 20pF 10 Ohm discharge = 250µjoule
   - For unknown victim - limit ESD discharge to 0.5µjoule
5. <u>Eliminate Ungrounded Conductors</u>



Background

- SCATHA Summary
  - From paper, instrument measured the coupling from ESD events into a 50 ohm and 10K ohm detector, shows that the radiated emissions from ESD can couple into wiring. Did not measure direct hits.
- CRRES
  - From papers, measured direct hits from different types of wiring and PCB configurations. Used 50 Ohm loads. Results into high impedance load not tested
  - Essentially Unshielded Wiring had few hits 10, Unshielded PCB had many >3000
  - “Safe Level” establish from unshielded PCB results. Real “Safe Level” of wiring TBD, Dielectric much thinner that PCB and therefore will stop fewer electrons. Published CRRES results have not taken thickness of dielectric and self shielding into account
  - Published CRRES result indicate that a long time, months, are required for dielectrics to reach steady state levels. Not clear how CRRES results apply to MAP 10 hour pass into belts every 7 days. Not clear that “Safe Level” applies for one 10 time period from approximately zero charge state (conclusion 8, Fig 2 note f, Fig 3)

Background

- Ground Testing
  - Coakley paper shows threat to wiring is due to electrons below 800Kev, Discharge voltage and current into 25 ohm detectors. Ungrounded conductors induce larger discharges.
    - Inner Discharges, dielectric to center conductor, were <0.1 amp < 15 ns,energy of 1.2 pico joules, frequency of discharge scales with cable length, amplitude independent of cable length
    - External Discharges, dielectric to shielding, scales with length of cable, Global discharges can be 5 amps lasting 100 ns with energies of 10 micro joules for 22 cm cables. These occurred at electron energies of 200KeV or less. At energies above 200 KeV local discharges occur
    - Arcs from unterminated conductors can induce large currents on neighboring conductors. Up to 1 amp current were measured.

Configuration of Other S/C

- General Configuration of GEO and HEO Spacecraft
  - S/C have outer skin and structure with honeycomb panels providing at least 20 mil Al shielding
  - It is recognized and expected that unavoidable dielectrics external to the spacecraft will discharge. Primarily surface discharges of Solar Array, Thermal blankets, ungrounded blankets and tape.
  - Outer skin provides Faraday cage to prevent the radiated emissions generated by external ESD from entering spacecraft internal cavity
  - Internal Harnesses not specifically shielded against electrons
  - External Harness shielded with braid and/or copper tape wrap. Where harness enters spacecraft Faraday Cage filters are installed or harness shield is tied to structure.
  - External signals that enter spacecraft Faraday cage are analyzed and filtered to prevent damage to electronics.

Spacecraft	Structure Shield	Internal Harness Shield	
GOES	0.020 + 0.010 Blankets	None	GEO
Voyager	0.079	None, External 0.005	Environment 100 x Earth
Galileo	0.060	None, External Braid	Environment 100 x Earth
Wind/Polar	?	Copper Tape	Various
ISSE	Honeycomb	?	Various
Image	0.020	None	HEO
HEO	Honeycomb	None	HEO

MAP Mission Requirement

- Mission Requirement

  No dielectric discharge shall cause damage to spacecraft circuitry or shall result in an upset or soft failure that aborts a mission critical maneuver.

  a) Limit the bulk resistivity of insulators to $<10^{12}$ Ohm-cm. (Nonobtainium)

  b) No ungrounded conductors are allowed

  c) Sufficient shields around cables to protect against circuit damage or upset from EMI fields emitted from surface or internal ESD elsewhere on spacecraft.

  d) No exposed voltages above 50 volts

Derivation Of Mitigation Approach

- The overall assessment of dielectric discharges is not an exact science. If you look to science or physics for how much a harness or dielectric will charge and then what the discharge is like and where it could strike, you will not get a definitive answer.
- The recommended guideline (NASA Handbook 4002) of 110 mil Al shielding results in excess of 30Kg mass increase. Most spacecraft do not provide this amount of shielding for their harness.
- Most spacecraft have survived dielectric charging threats without detailed analysis or design rules. We need to continue to build spacecraft with the big picture in mind and not do something drastically different from previous experience.
- This experience is based on the spacecraft structure providing shielding for the internal harness and providing special filtering for any harness that transitions to the exterior of the structure.
- The MAP approach provides a 7.8 mil copper shield to bring the overall shielding to the equivalent of a ”typical” spacecraft with 20 mil Al from honeycomb facesheets.
- Detailed analysis performed by Aerospace will support the amount of shielding necessary to reduce the electron flux to levels that pose an acceptable risk.

a) Bulk Resistivity

Limit the bulk resistivity of insulators to $<10^{12}$ Ohm-cm. Or:

- Limit the electron flux to insulators by shielding to 10^{10} electrons/cm^2 in 10 hours or:
  - For harnessing: Plate shielding or wrapping with 20 mil Al equivalent (6 mil Copper, 4 mil Lead, or 3.5 mil Tantalum) reduces electron flux by factor of 100. Shield to cover 99.9% of sphere. Shields around cables (conductors around dielectrics) wrapped to limit "gaps" to 1 sq inch, 6.5 sq cm.
- Filter nearby circuitry to withstand a 5000 volt 20pf 10 ohm discharge or:
  - Detailed analysis of discharge could result in smaller or larger discharge source than above. Assess discharge threat to circuits that can not be totally shielded. Such as antennas, umbilical connector, thermistors, PRTs, heaters, Solar Array, CSS. If necessary implement filters to protect these circuits.
- Coat the exterior surface of the dielectric with a grounded layer with resistivity $<10^9$ ohm/square or:
- Prevent the discharge from reaching a victim circuit by shielding and or introducing a grounded conductive barrier.

b) Ungrounded Conductors

No ungrounded conductors are allowed

This includes unused wires in harnesses, unused or unpopulated circuit board traces, ungrounded IC, relay, transformer cores, transistor or capacitor cases, spare pins in connectors, thermal blankets, Aluminum or Copper tape, ungrounded bracketry, harness tie downs for harness or connectors.

- Exceptions are allowed by waiver if analysis shows no direct or radiated path to victim circuitry exists or victim can survive discharge.
  - Keep the quantity and size of the ungrounded conductors as small as possible.
  - Interrupt the path between the ungrounded conductor and sensitive circuitry. Provide a conductive barrier between the ungrounded conductor and a victim circuit. This conductive barrier can be the copper tape wrap or a grounded thermal blanket. This conductive barrier would serve as the nearest victim for a discharge and therefore protect the harness from a direct hit.
- Allow ungrounded conductors as long as there is the equivalent of 110 mil Al shielding

c) EMI Shielding

- Sufficient shields around cables to protect against circuit damage or upset from EMI fields emitted from surface or internal discharges elsewhere on spacecraft.
  - 100% coverage of harness, connector and backshell. Tape grounded at both ends. Mechanism to assure that individual sections of tape remain grounded.

d) Exposed Voltages

- No exposed voltages above 50 volts

Not a concern. MAP has no voltages above 35 volts including the Solar Array.

Environment

- MAP Orbit
- L Levels
- Integrated Flux, CRRES, AE8

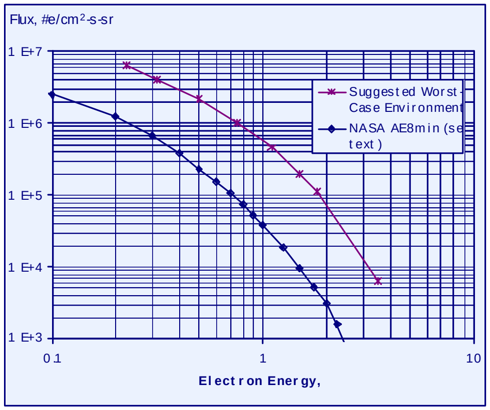


FIGURE 6. GEO Electron Flux Greater than Specified Energy

Upper: Worst-Case Short-Term GEO Environment (May 11 1992, 197 degrees East Longitude peak daily environment over several hour period, with no added margin.)
Lower: NASA AE8min Long-Term Average Environment (200 degrees East Longitude)
Daily fluence converted to flux per second and from omnidirectional to "per sr" units

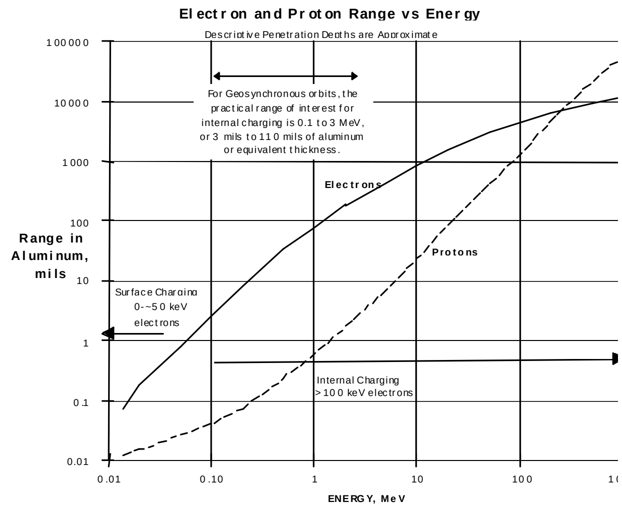


FIGURE 3. Electron/Proton Penetration Depths in Aluminum

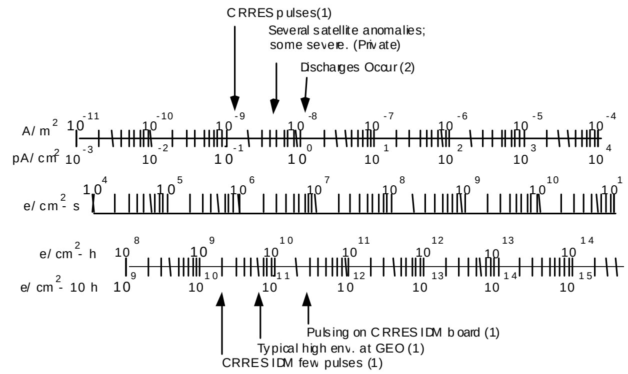


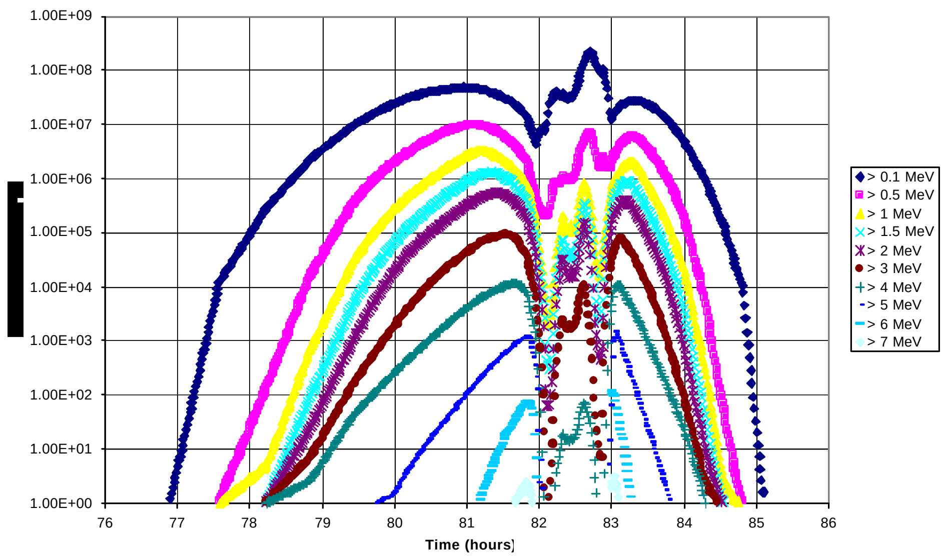
FIGURE 5. IESD Hazard Levels versus Electron Flux (Various Units)

(1) Frederickson [1992], (2) Robinson [1989], and others.

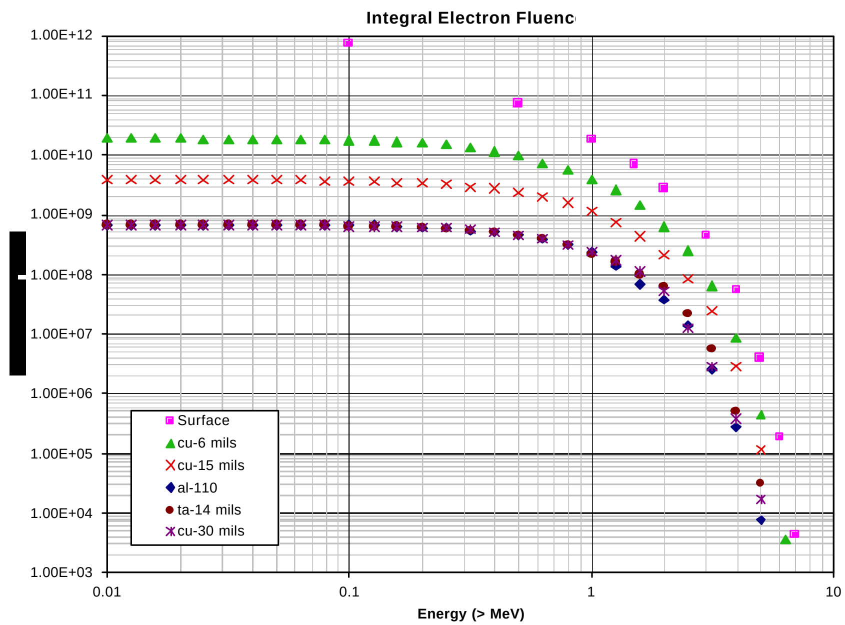
See Appendix F, Section F.3 for information about CRRES.

AE8

Integral Electron Flux Along Orbit P
MAP Transfer Trajectory - A3-P3

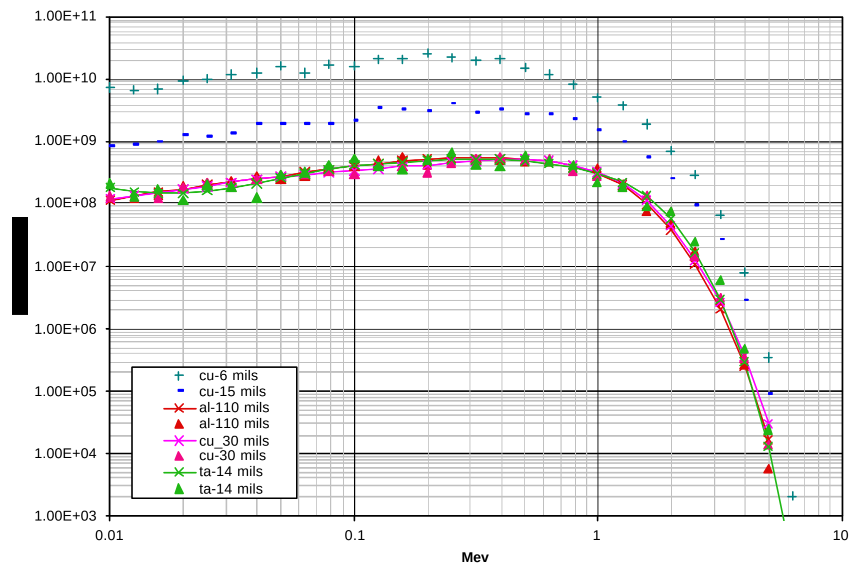


AE8


Integral Electron Fluenc
1.00E+12
1.00E+11
1.00E+10
1.00E+09
1.00E+08
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
0.01
0.1
1
10
Energy (> MeV)
Surface
cu-6 mils
cu-15 mils
al-110
ta-14 mils
cu-30 mils

AE8

Differential Fluence



Shielding Analysis

- Cable Analysis
- Flux Behind Thermal Blanket and Shield

Dielectric and Floating Conductor Charging

- Dielectrics Inventory
- Floating Conductor Inventory
  - Floating conductors can provide a large capacitance and large discharge when compared to the discharge of a wire harness dielectric
    - 1” x 6” tape with .005” adhesive has a 200pf capacitance
    - 100 sq cm ungrounded .005” from chassis has a 500pf capacitance

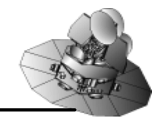
Discharge Threat

- Interface Circuit Summary

Mitigation Plan

- Grounding
- Shielding Plan
- Filtering

Grounding



- Ground All External Surfaces >100 sq cm TBR
  - $<10^9$ Ohms/square surface resistivity
  - Thermal blankets <1K to chassis
- Ground All Internal Conductors
  - Where Grounding is impractical:
    - Provide 110 mil Al shielding, or:
    - Provide a grounded conductive barrier or shield between the ungrounded conductor and victim circuitry, or:
    - Assure victim can survive discharge energy
  - Compile a list of ungrounded conductors and verify with above acceptance criteria.

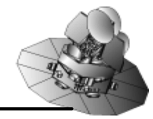
Shielding Plan

- Wrap all harnesses with three layers of 2.6 mil copper tape. 1700 feet at 8 Kg min for total harness. Ground tape to connector backshells.
  - 2.6 mil Cu tape turns out to have only 1.4 mil Cu, will need more layers or use 4 mil of lead
- Wrap a “drain wire” around the cu tape to assure all sections of tape are grounded. Connect drain wire to connector backshell with lugs under mounting screw.
- Wrap harness that is flexed during box installation and integration with Kapton tape.
- Identify wiring that is not totally shielded by the copper foil. Assess discharge threat and potentially install filter pin connectors.
- The copper foil also functions as a shied to attenuate the EMI pulses that maybe generated by surface or dielectric ESD.
- Assess the details of the rework plan and verification approach [Demate (maybe remove) boxes, wrap harness foil/kapton, verify pin retention, safe-to-mate-test, reintegrate boxes.]

Filtering

- Thermistor circuits
  - Filter pin connectors installed as “connector savers”
  - Filter pin connectors need 1600pf capacitance
    - Capacitance is large (x 10 to x 1000) when compared to harness discharge, discharge voltage is divided by capacitance ratio
    - Capacitance maybe small when compared to a floating dielectric, may not be able to filter floating conductor discharges
    - Filters Radiated pickup from discharges elsewhere

Summary & Conclusion



- 7.8 mil Copper or 4 mil Lead (EMI shielding ability TBR) is adequate for MAP Orbit based on lower flux than CRRES flight cables with no discharges in worst case MAP environment (20 year storm)
  - Compute Electron Flux on CRRES Wire samples and Channel 16 PCB in CRRES orbit
  - Verify Dimensions and density of GORE wire from actual measurements
  - Decide on flight shielding layup (Cu or Pb or Pb with Cu)
  - Plot the integral and differential flux form MAP behind 3 mil Mylar and the Mylar plus the 4 mil lead
  - Reconcile CRRES 50 Ohm detector vs MAP 2400 Ohm load
- Do not use a new harness insulating material (carbon loaded Teflon) without a radiation test that shows the new insulation works
- Aerospace Recommends an ESD test per MIL-1541
  - Choose discharge energy based on expected on orbit discharge
- Re evaluate maximum allowed size (100 cm^2) for largest ungrounded blanket or floating conductor
- Define adequate EMI shield, test new and non standard shields (VDA2 Kapton, Pb)
  - Evaluate the RF emission spectrum from measured ESDevents
- Details
  - Generate Source to Victim Matrix
  - Resolve ungrounded connector pin issue (JPL criteria 25 cm ungrounded wire total)
  - Complete the Interfaces, Dielectric and Ungrounded Conductor Summaries
  - Contact lead tape users for process and safety issues