Electromagnetic Compatibility
Space System Design, MAE 342, Princeton University
Robert Stengel

- Problems, Analysis, and Testing
- Specifications
- Fundamentals
- Systems Approach
- Categories
- Spacecraft Charging
- Electrostatic Discharge
- Grounding Schemes
- Special Problems of Small Satellites

Copyright 2016 by Robert Stengel. All rights reserved. For educational use only. http://www.princeton.edu/~stengel/MAE342.html

Electromagnetic Compatibility Goals

- No interference between systems or components
- Systems not susceptible to E/M emissions from any source
- No internal interference within a system
- Examples of incompatibility
  - Static, buzzes, clicks
  - Electrostatic discharge
  - Components with different grounding
EMC Specifications

• Enumerated in standards and mission-specific documents
  – MIL-STD (US military)
  – CE (Conformité Européenne)
• Various levels of requirements
• Details of verification
  – Inspection
  – Analysis
• System design guidelines
• Limitations imposed by specialized payloads

Terms and Definitions

• EMC
• EMI
• RFI
• ESD
• EMP
Fundamental Compatibility Issues

- Source of emissions
- Receiver of emissions
- Transfer or coupling that facilitates interference
- Possible fixes
  - Reduce emissions
  - Alter the coupling path
  - Make the receiver less susceptible
  - Error-correction coding

Systems Approach to EMC

- Top-down (performance-driven) approach
- Safety margins and budgets
  - Level of emissions
  - Definition of “worst case” limits

GWEC, 2001
Categories of EMC

Radiated

Radiated emissions or radiated susceptibility

- Electric fields
  - RF
    - 3kHz-3000GHz
- DC magnetic fields
- AC magnetic fields
  - picoTeslas
    - 0.05-100KHz

Susceptibility: Emissions picked up by harness or cables

Categories of EMC

Conducted

Conducted emissions or conducted susceptibility

- Power lines
- Signal lines
  - Differential mode
  - Common mode
  - Differential mode
  - Common mode
External Sources: 
*Magnetosphere and Van Allen Belts*

Trapped Energetic Ions and Electrons
Light ions form base population of the magnetosphere

Earth's Dipolar Magnetic Field

\[ B(R_0, \lambda) = \frac{\left(1 + \sin^2 \lambda \right)^{1/2}}{R_0^3} B_0 \]

\[ B_0 = 0.3 \text{ Gauss} \]

*Fortescue, et al., 2011*
Integral Electron Flux Contours at Earth, Jupiter, and Saturn

High-Energy Proton Flux in Inner Van Allen Belt
Spacecraft Charging Hazard Zones

Interaction of sunlight, space plasma, and spacecraft materials and electronics
Spacecraft Charging Damage

Interaction of space plasma and spacecraft materials and electronics

SCATHA Satellite, 1979

(a) Failure caused by in-flight ESD arcing

Proton and Electron Penetration in Aluminum

NASA-HDBK-4002A, 2011
### Acceptable Surface Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paint (carbon black)</td>
<td>Work with manufacturer to obtain paint that satisfies ESD conductivity requirements of Section 3.2.2 and thermal, adhesion, radiation tolerance, and other needs.</td>
</tr>
<tr>
<td>GSFC NS43 paint (yellow)</td>
<td>Has been used in some applications where surface potentials are not a problem; apparently will not discharge.</td>
</tr>
<tr>
<td>ITO (250 nm)</td>
<td>Can be used where some degree of transparency is needed; must be properly grounded. For use on solar cells, optical solar reflectors, and Kapton® film, use sputtered method of application and not vapor deposited.</td>
</tr>
<tr>
<td>Zinc orthotitanate paint (white ZOT)</td>
<td>Possibly the most conductive white paint; adhesion difficult without careful attention to application procedures, and then difficult to remove.</td>
</tr>
<tr>
<td>Alodyne</td>
<td>Conductive conversion coatings for magnesium, aluminum, etc., are acceptable.</td>
</tr>
<tr>
<td>DuPont Kapton® XC family</td>
<td>Carbon-filled polyimide films; 100XC1037 with nominal resistivity of 2.5 x 10^6 Ω-cm; not good in atomic oxygen environment without protective layer (ITO, for example).</td>
</tr>
<tr>
<td>Deposited conductors</td>
<td>Examples: aluminum, gold, silver, Inconel® on Kapton®, Teflon®, Mylar®, and fused silica.</td>
</tr>
<tr>
<td>Conductive paints</td>
<td>Over dielectric surfaces, with some means to assure bleed-off of charge.</td>
</tr>
<tr>
<td>Carbon-filled Teflon® or Kapton®</td>
<td>Carbon filler helps make the material conductive.</td>
</tr>
<tr>
<td>Conductive adhesives</td>
<td>Especially if needed for bridging between a conductor and ground.</td>
</tr>
<tr>
<td>Conductive surface materials</td>
<td>Graphite epoxy (scuffled to expose carbon fibers) or metal.</td>
</tr>
<tr>
<td>Etched metal grids</td>
<td>Etched or bonded to dielectric surfaces, frequent enough to have surface appear to be grounded.</td>
</tr>
<tr>
<td>Aluminum foil or metalized plastic film tapes</td>
<td>If they can be tolerated for other reasons such as thermal behavior.</td>
</tr>
</tbody>
</table>

### Unacceptable Surface Materials

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anodize</td>
<td>Anodizing produces a high-resistivity surface to be avoided for ESD applications. The coating can be made quite thin and might be acceptable if analysis shows stored energy is small.</td>
</tr>
<tr>
<td>Fiberglass material</td>
<td>Resistivity is too high and is worse at low temperatures.</td>
</tr>
<tr>
<td>Paint (white)</td>
<td>In general, unless a white paint is measured to be acceptable, it is unacceptable.</td>
</tr>
<tr>
<td>Mylar® (uncoated)</td>
<td>Resistivity is too high.</td>
</tr>
<tr>
<td>Teflon® (uncoated)</td>
<td>Resistivity is too high. Teflon® has demonstrated long-time charge storage ability and causes catastrophic discharges.</td>
</tr>
<tr>
<td>Kapton® (uncoated)</td>
<td>Generally unacceptable because of high resistivity; however, in continuous sunlight applications if less than 0.13 mm (5 mil) thick, Kapton® is sufficiently photoconductive for use.</td>
</tr>
<tr>
<td>Silica cloth</td>
<td>Has been used for antenna radomes. It is a dielectric, but because of numerous fibers or if used with embedded conductive materials, ESD sparks may be individually small. It has particulate issues, however.</td>
</tr>
<tr>
<td>Quartz and glass surfaces</td>
<td>It is recognized that solar cell cover glasses and second-surface mirrors have no substitutes that are ESD acceptable; they can be ITO coated with minor performance degradation, and the ITO must be grounded to chassis. Their use must be analyzed and ESD tests performed to determine their effect on neighboring electronics. Be aware that low temperatures significantly increase the resistivity of glasses [3].</td>
</tr>
</tbody>
</table>
Differential Solar Charging and Modeling

Conducted Emissions/Susceptibility: *Differential Mode and Common Mode Interference Probing*

Subsystem 1

<table>
<thead>
<tr>
<th>Signal drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

Differential mode current probe = $I_1$

(to ground)

Common mode current probe = $I_1 - I_2$

Subsystem 2

Signal receiver

$F$eretecue
Electrostatic Discharge (ESD)

- Always a “spark”
- Radiated effect
  - RF signal due to distant pulse
  - Testing for radiated emissions from ESD
- Conducted effect
  - Discharge picked up by conducting element of the spacecraft
  - Possibility of high current

Protection Against ESD

- Location of components
- Grounding
- Bonding (~soldering)
- Isolation (“Faraday cage”, “mu metal”)
- Power supply to components
  - Direct
  - Regulated
  - Converted
- High-impedance semiconductors (e.g., MOS)
- Less sensitive components (e.g., vacuum tubes!)
- Procedures in preparation of spacecraft
Spacecraft Grounding

- Reference point
  - 0V, earth, common, ground, chassis
- Current between “grounded” components may not be zero
  - Small potential between end points
  - Resistance and inductance of wire
- Minimize signal “cross talk” or power supply voltage differences
- Grounding techniques

Single-Point Grounding

- Diagram showing single-point grounding connected to spacecraft structure
- Example of signal current flow between subsystems
- Use of converters and isolation to manage power supply voltages
Multi-Point Grounding

Hybrid Grounding
Major Causes of EMC Problems:

**Power Supplies**

- Switch mode power converters
- Transistor operating speed
- Switched voltage and current levels
- Stray capacitance
- Copper foil shields
- Diodes

Major Causes of EMC Problems:

**DC Motors and Actuators**

- Inductive nature
- PWM
- Rise/fall times
- Avoidance techniques
Major Causes of EMC Problems:
Harnesses and Cables

- Passive, yet major source of interference
- Grounding and bonding
- Matched drivers, transmitters, and cables
- Slow down rise and fall times
- Screened or twisted cables
- Filtering at connectors
- Impedance matching

Analysis Methods

- Example: PSpice

- Example: MATLAB: various books and EMPLab
EMC Testing

- Open-air test sites
- Anechoic and reverberation test chambers
- Spectrum analysis
- High-powered pulse or signal generator


Small Satellite Design Philosophy

- Conventional Mission
  - Reduced risk
  - Increased cost
- Fewer missions
- Managed risk
- More missions
- Reduced cost
- Small Satellite Mission

Fortescue
Small Satellite System Design

Use of Commercial-Off-the-Shelf (COTS) Technology
Effects of Ionizing Radiation on COTS Components

- Total dose effects
- Single-event upsets/latchup
- Regular “washing” of memory
- Spot shielding
- Radiation hardening

after Fortescue

Case Study: StangSat Testing

- Project at NASA KSC
- EM conduction and radiation testing: MIL-STD-461F, RE102 Limits

See Lecture 19 Course Materials on Blackboard
Next Time:
Spacecraft Mechanisms