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

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 Européene)*
- Various levels of requirements
- Details of verification
  - Inspection
  - Analysis
- System design guidelines
- Limitations imposed by specialized payloads

Terms and Definitions

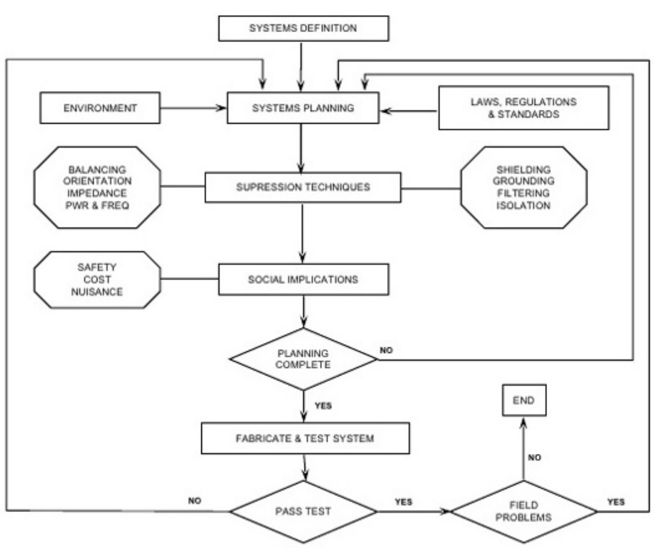
- EMC
- EMI
- RFI
- ESD
- EMP

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**

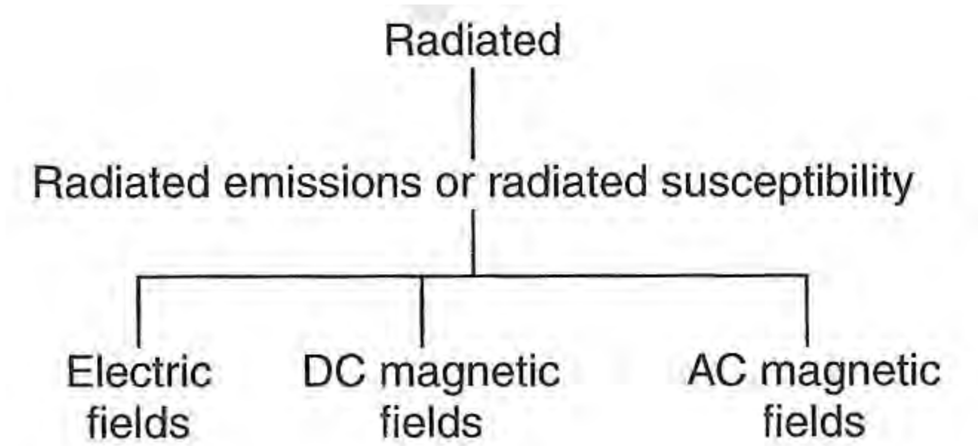
Systems Approach to EMC

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



GWEC, 2001

Categories of EMC



RF
3KHz-3000GHz

picoTeslas

picoTeslas
0.05-100KHz

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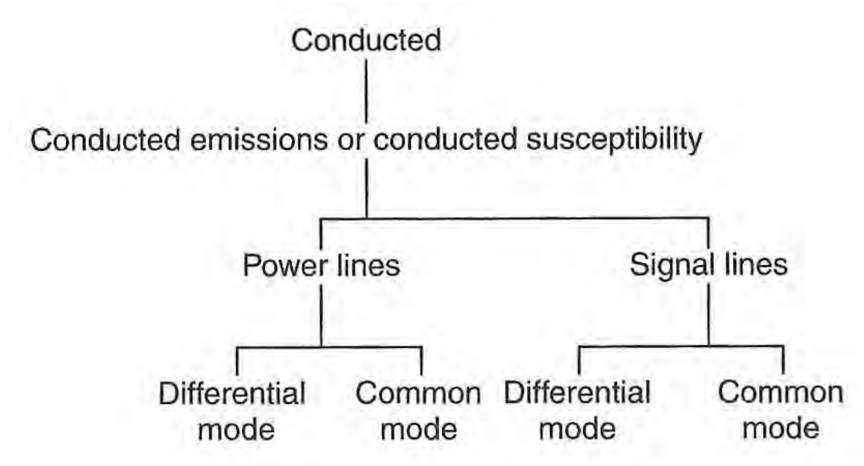
Susceptibility: Emissions picked up by harness or cables

Categories of EMC



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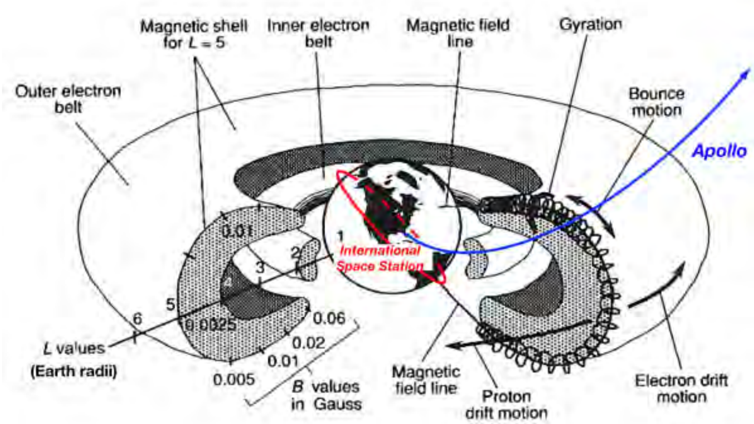
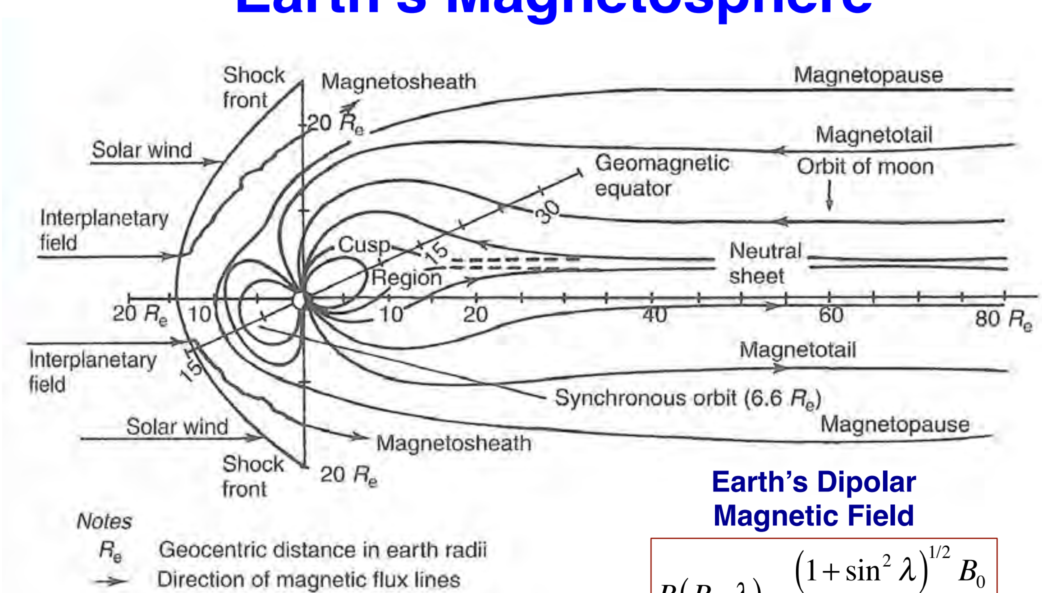
External Sources:
Magnetosphere and Van Allen Belts

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



Earth's Magnetosphere



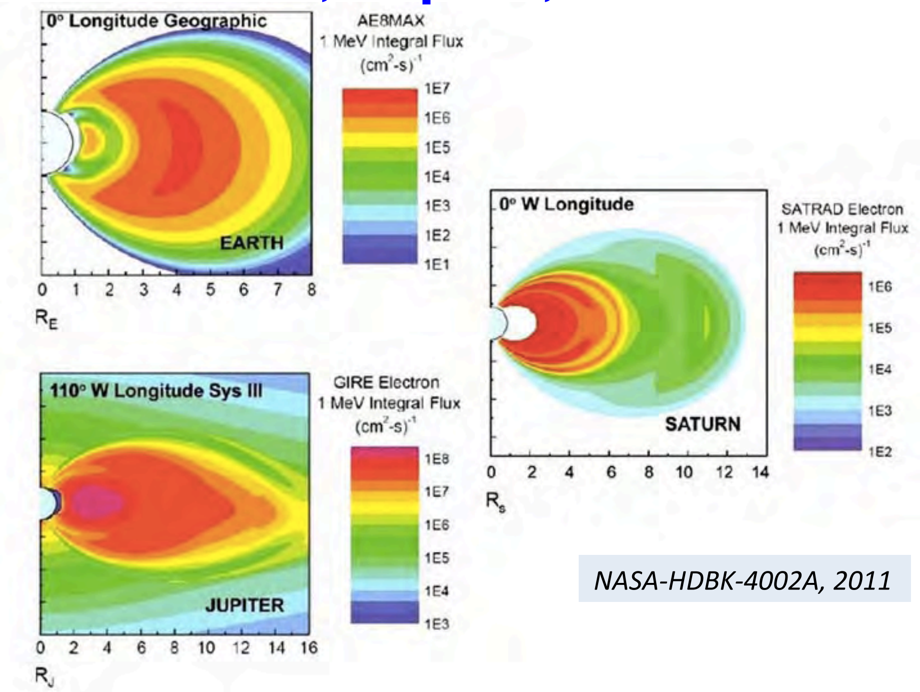
Fortescue, et al, 2011

Earth's Dipolar Magnetic Field

$$B(R_e,\lambda)=\frac{\left(1+\sin^2\lambda\right)^{1/2}B_0}{R_e^{\;3}}$$

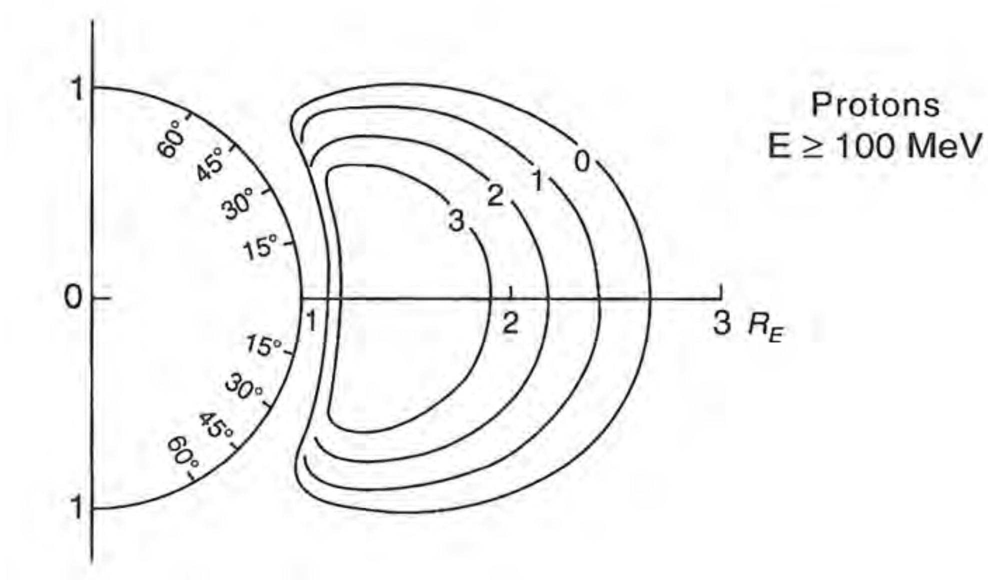
$$B_0 = 0.3 \text{ Gauss}$$

Integral Electron Flux Contours at Earth, Jupiter, and Saturn

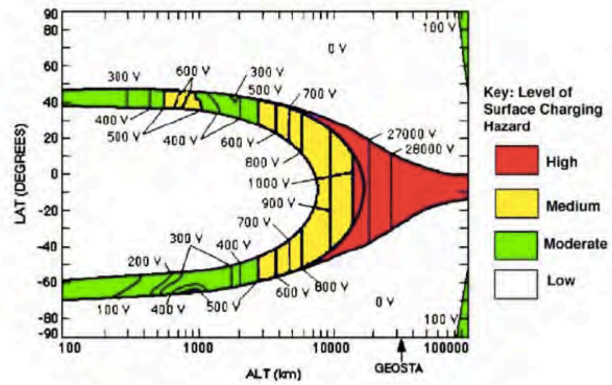


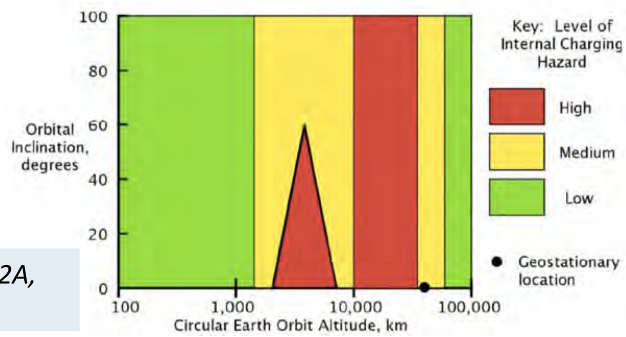
NASA-HDBK-4002A, 2011

High-Energy Proton Flux in Inner Van Allen Belt



Spacecraft Charging Hazard Zones



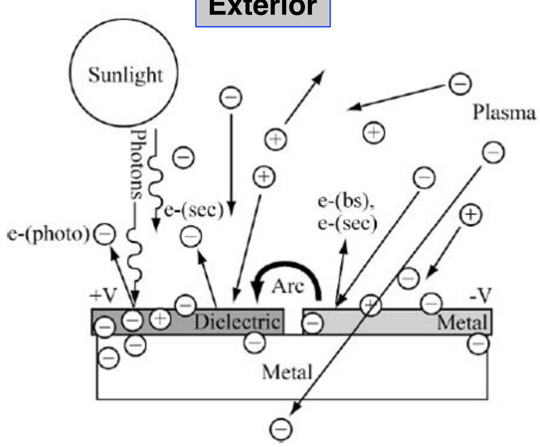


NASA-HDBK-4002A, 2011

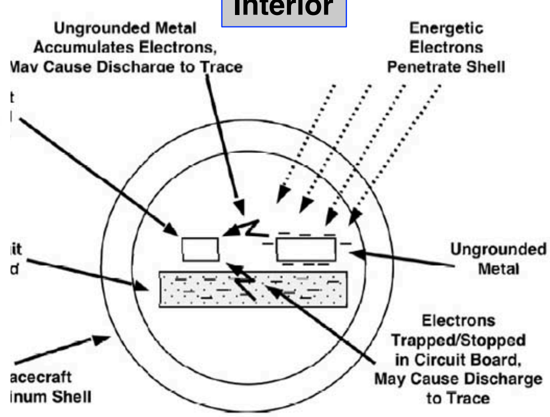
Spacecraft Charging

Interaction of sunlight, space plasma, and spacecraft materials and electronics

Exterior



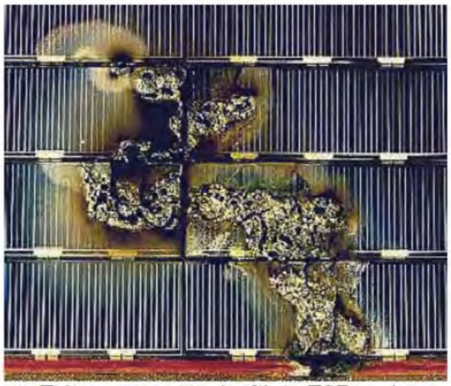
Interior



NASA-HDBK-4002A, 2011

Spacecraft Charging Damage

Interaction of space plasma and spacecraft materials and electronics

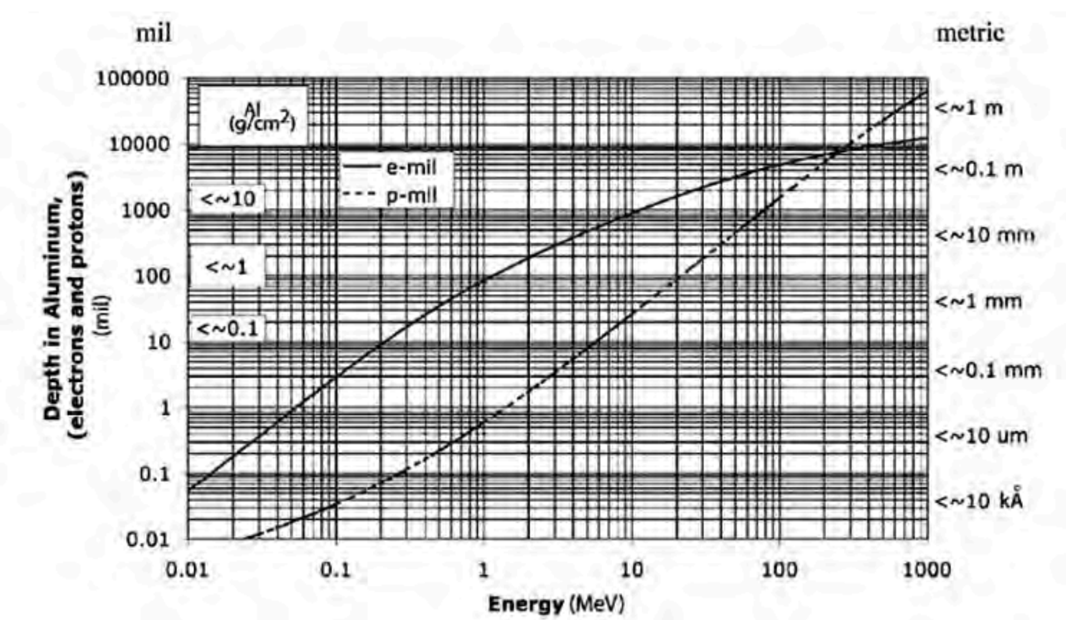


(a) Failure caused by in-flight ESD arcing

SCATHA Satellite, 1979

NASA-HDBK-4002A, 2011

Proton and Electron Penetration in Aluminum



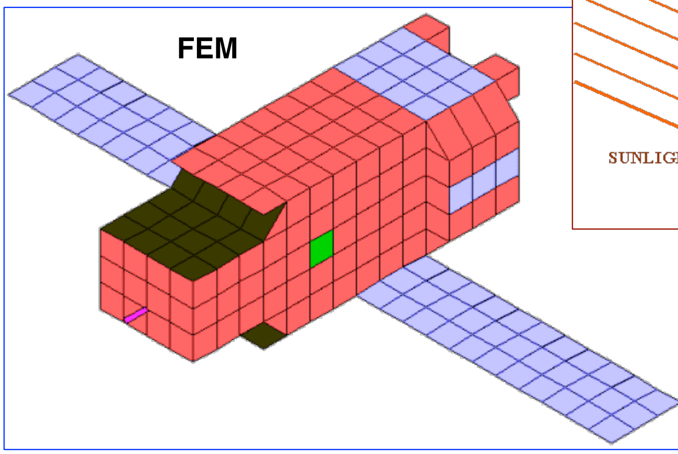
Acceptable Surface Materials

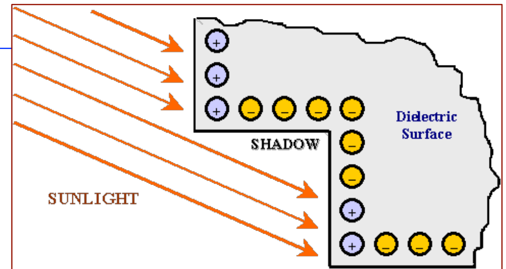
Material	Comments
Paint (carbon black)	Work with manufacturer to obtain paint that satisfies ESD conductivity requirements of Section 3.2.2 and thermal, adhesion, radiation tolerance, and other needs.
GSFC NS43 paint (yellow)	Has been used in some applications where surface potentials are not a problem; apparently will not discharge.
ITO (250 nm)	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.
Zinc orthotitanate paint (white ZOT)	Possibly the most conductive white paint; adhesion difficult without careful attention to application procedures, and then difficult to remove.
Alodyne	Conductive conversion coatings for magnesium, aluminum, etc., are acceptable.
DuPont Kapton® XC family	Carbon-filled polyimide films; 100XC10E7 with nominal resistivity of 2.5×10^4 Ω-cm; not good in atomic oxygen environment without protective layer (ITO, for example).
Deposited conductors	Examples: aluminum, gold, silver, Inconel® on Kapton®, Teflon®, Mylar®, and fused silica.
Conductive paints	Over dielectric surfaces, with some means to assure bleed-off of charge.
Carbon-filled Teflon® or Kapton®	Carbon filler helps make the material conductive.
Conductive adhesives	Especially if needed for bridging between a conductor and ground.
Conductive surface materials	Graphite epoxy (scuffed to expose carbon fibers) or metal.
Etched metal grids	Etched or bonded to dielectric surfaces, frequent enough to have surface appear to be grounded.
Aluminum foil or metalized plastic film tapes	If they can be tolerated for other reasons such as thermal behavior.

MATERIAL	COMMENTS
Anodyze	Anodyzing 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.
Fiberglass material	Resistivity is too high and is worse at low temperatures.
Paint (white)	In general, unless a white paint is measured to be acceptable, it is unacceptable.
Mylar® (uncoated)	Resistivity is too high.
Teflon® (uncoated)	Resistivity is too high. Teflon® has demonstrated long-time charge storage ability and causes catastrophic discharges.
Kapton® (uncoated)	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.
Silica cloth	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.
Quartz and glass surfaces	It is recognized that solar cell cover slides 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].

Unacceptable Surface Materials

Differential Solar Charging and Modeling



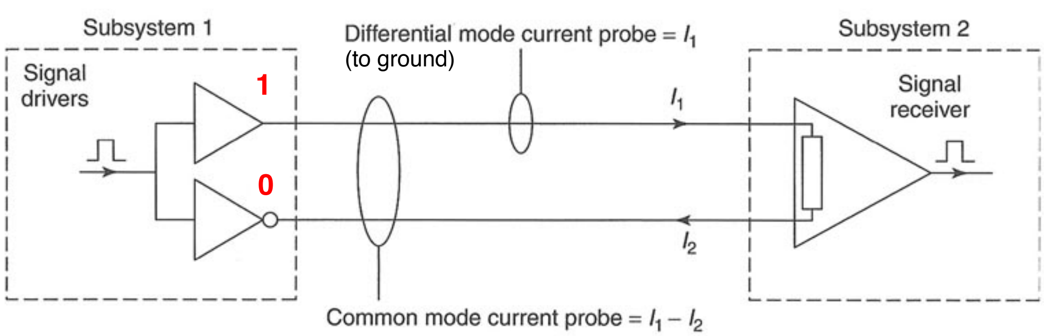


Herr, NASA

Holbert, 2006

Conducted Emissions/Susceptibility:

Differential Mode and Common Mode Interference Probing



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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**

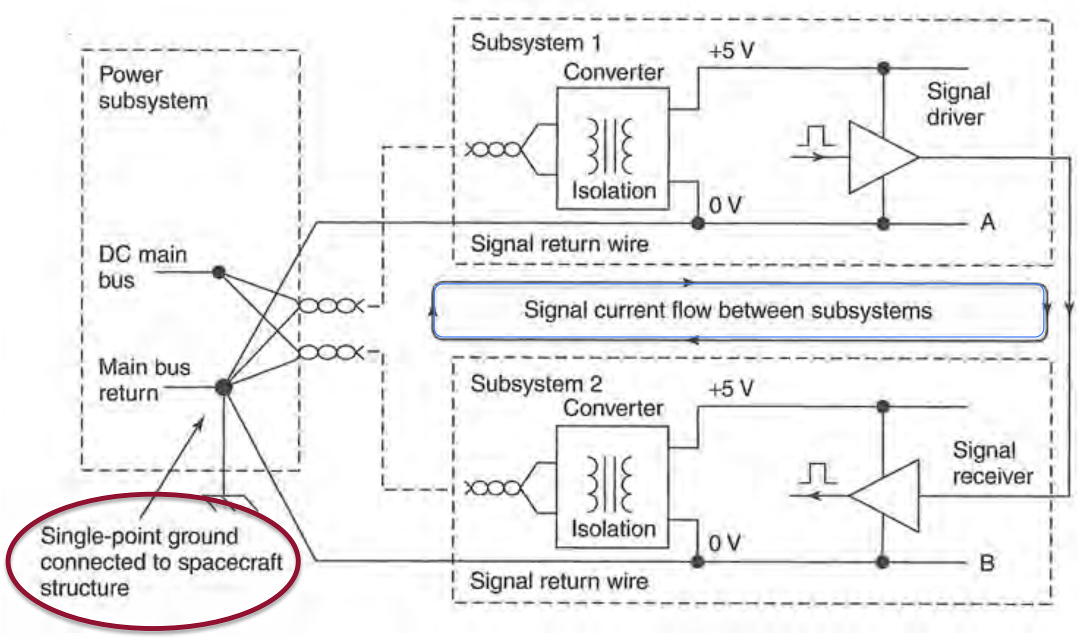
Protection Against ESD

- **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



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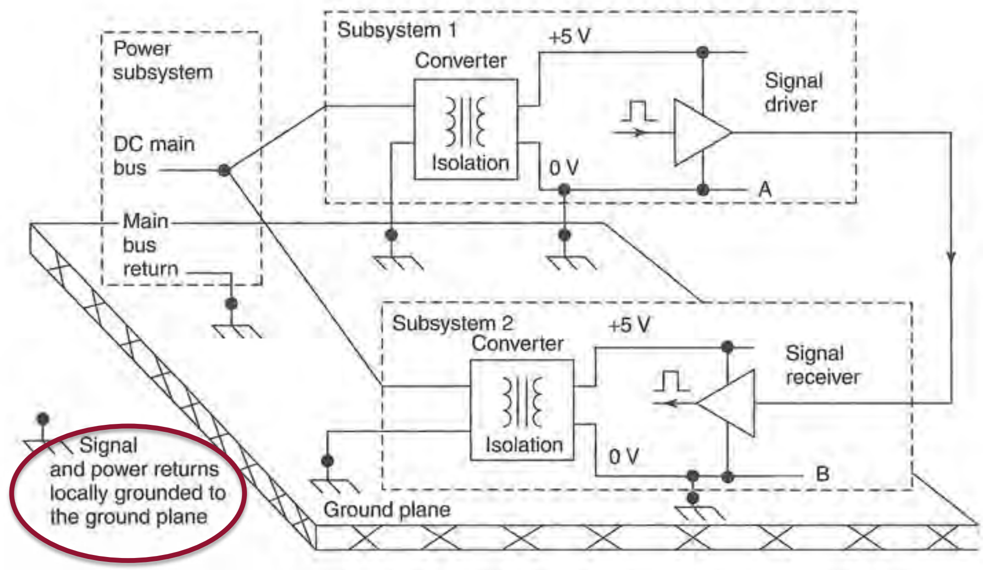
Multi-Point Grounding



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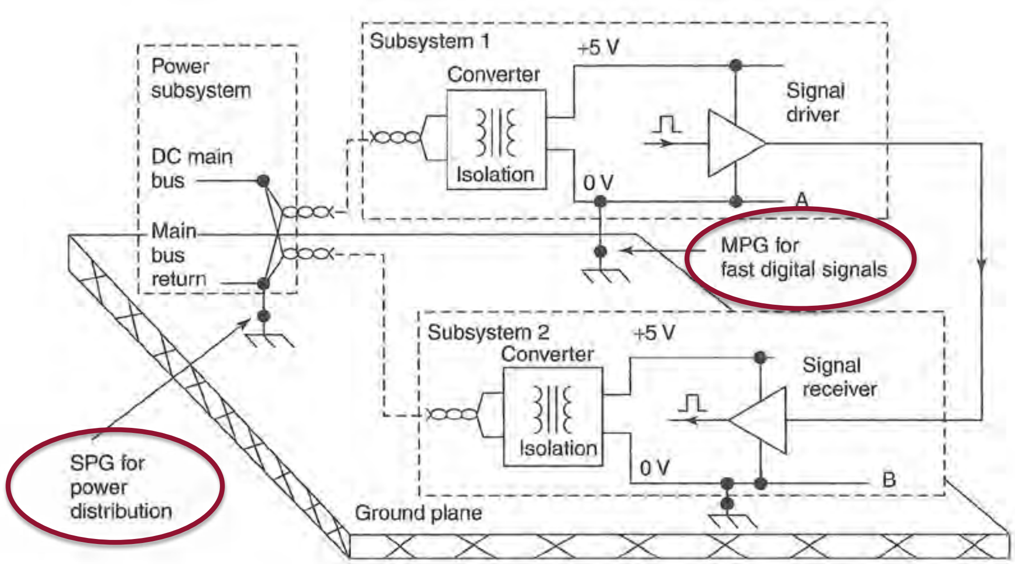
Hybrid Grounding



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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

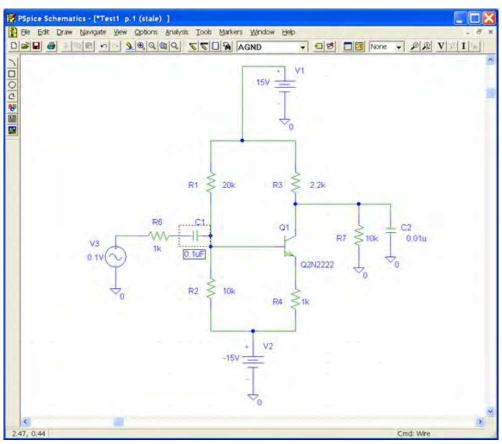
- Inductive nature
- PWM
- Rise/fall times
- Avoidance techniques

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

https://en.wikipedia.org/wiki/Electromagnetic_compatibility

Small Satellite Design Philosophy

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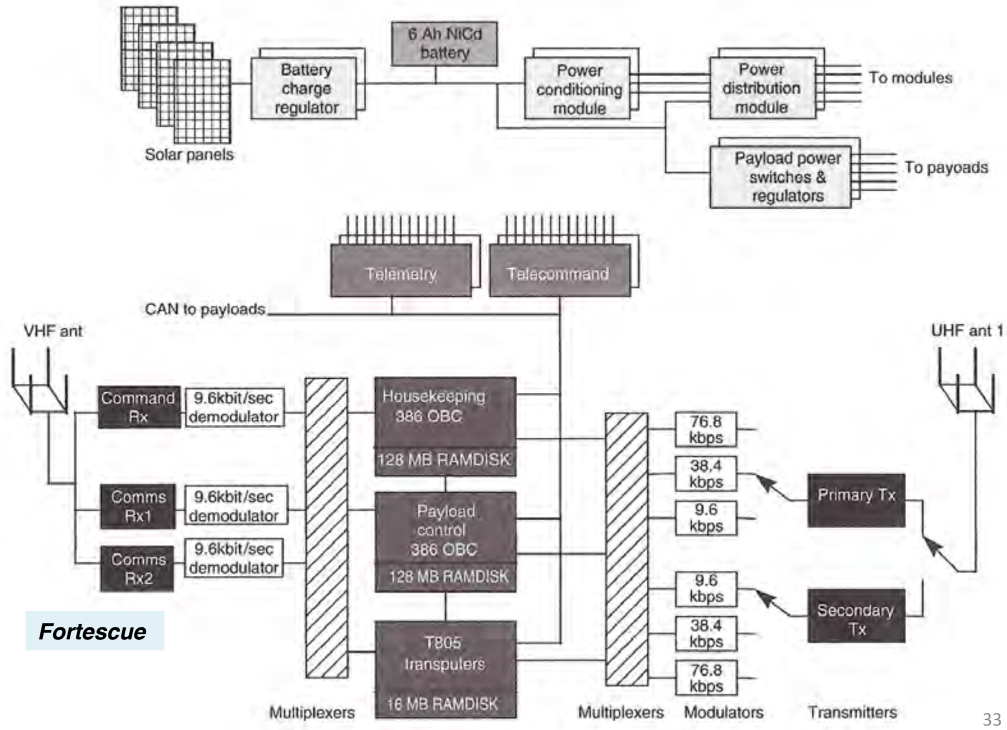
Small Satellite System Design



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Use of Commercial-Off-the-Shelf (COTS) Technology

Microsatellite	Main On-Board Computer Processors (subsystem microcontrollers and payload processors not included)			
	1802	Z80	80C186	80386EX
UoSAT-2 (1984)	Primary			
UoSAT-3 (1990)	Primary (back-up)	Secondary (experimental)	Primary (experimental)	
UoSAT-5 (1991)		Secondary	Primary	
KITSAT-1 & S80/T (1992)		Secondary	Primary	
PoSAT-1 & HealthSat-2 (1993)			Primary	
Cerise (1995)			Primary	
FASat-Bravo & Thai Phutt (1998)			Secondary	Primary (experimental)
Subsequent Missions (1999–2009)				Primary

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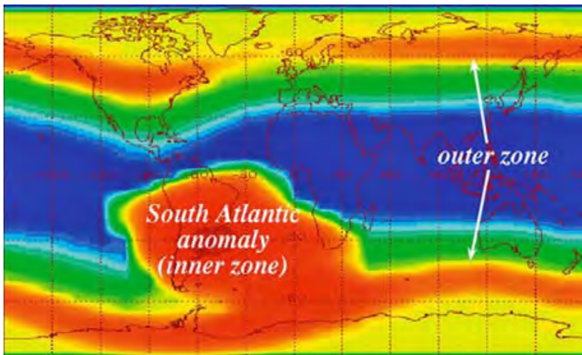
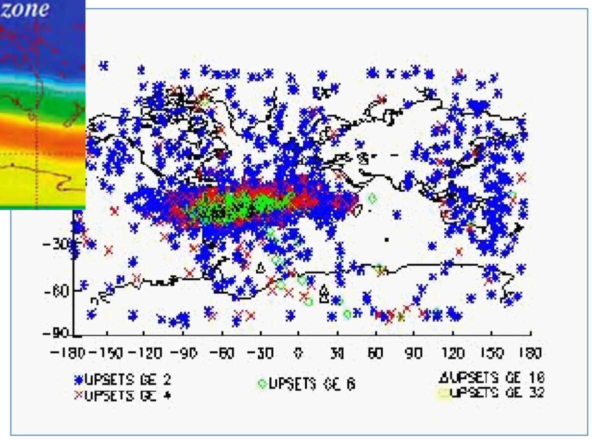
Effects of Ionizing Radiation on COTS Components



- Total dose effects
- Single-event upsets/ latchup

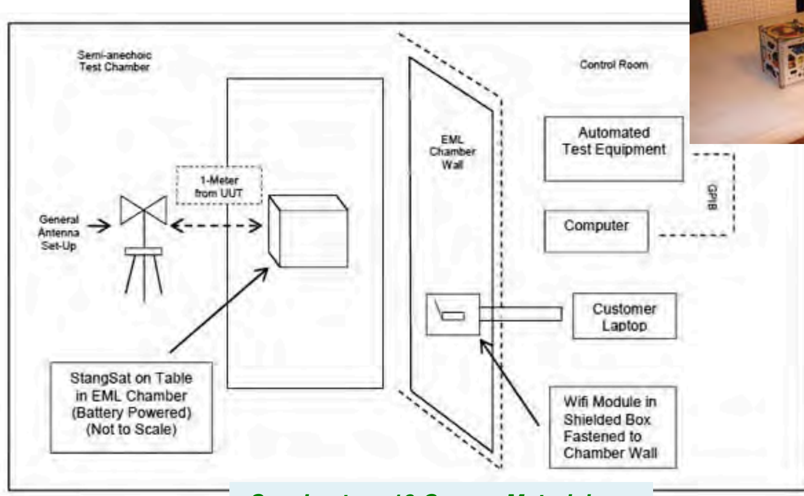


- Regular "washing" of memory
- Spot shielding
- Radiation hardening

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