A Unified Topological Approach to Electromagnetic Environmental Effects Protection

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Available at: https://works.bepress.com/george_h_baker/16/
A Unified Topological Approach to Electromagnetic Environmental Effects (E³) Protection

EMP and EMC for Civil Systems Session

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2nd International Symposium on Electromagnetic Compatibility (EMC) and Electromagnetic Ecology (EME)

St. Petersburg, Russia

26-30 June 1995
OUTLINE

- Motivating factors
- Examples of EM effects
- Dominant EM effects concept
- Technical basis
- Generalized approach
- Summary
MOTIVATING FACTORS

- Reduction of costs and increased value of system acquisition
- Systems with multiple EM effects requirements
- Growing dependence on electronics of increasing susceptibility
- Consolidation of EM design / protection standards
- Consolidation of test requirements and test facilities
- Development of consistent commercial and military EM standards
- Potential for considerable cost savings
EXAMPLES OF EM EFFECTS

- TEMPEST
- HPM, UWB
- EMP
- HEMP
- SREMP
- SGEMP / IEMP
- DEMP
- Lightning
- ESD
- EMC / EMI
- ECM / ECCM
- EMR (O/H)
- RADHAZ, HERO
EXAMPLES OF EM EFFECTS:

HPM

Typical HPM parameters:
- Frequency range: 0.3 to 10 GHz / 100 GHz
- Pulse width: nanoseconds to microseconds
- Peak power: 0.1 to 10 GW
- Repetition rate: 10 to 100 Hz

Impacts wide spectrum of systems
EXAMPLES OF EM EFFECTS:

NUCLEAR EMP

- Produced by high altitude (> 40 km) burst
- Time-domain peak electric fields of 50 kV/m
- Frequency components to 100 MHz
- Affects wide spectrum of systems
- Wide area coverage
Expected cost of failure = expected failure rate \times \text{cost per failure}

- Define the EM effects with the greatest expected failure cost as the Dominant EM effects
- Goal is to reduce expected cost to acceptable level
- The acceptable cost level threshold may occur when \( \Delta \text{cost of protection} \approx \Delta \text{cost of failure without protection} \)
DEFENSE NUCLEAR AGENCY

TECHNICAL BASIS

- Define applicable EM effects and determine those that dominate

- A single generalized barrier can moderate the Dominant EM effects
  - Barrier may be shaped or distributed as required
  - Penetration protection provided
  - Validation testing requirements are a function of barrier design and acceptable risk

- Difficulties
  - Very wide EM effects amplitude and frequency coverage
  - Large variation of equipment technology, location, and function
  - EM effects sources may be located externally or internally
Designs exist that employ shielding and TPDs for protection from individual threat environments.

Therefore, it is conceptually feasible to combine them into a single integrated protection design.

The challenge is to reduce redundancy in order to reduce costs through:
- Selecting the Dominant EM effects
- Common design
- Common validation testing
- Maintenance
- Balancing the cost of implementing protection with the cost of failure
A system may be viewed as being adequately protected if

System EM effects strength > system EM effects stress + margin

- System EM effects strength determined by critical subsystem susceptibilities
- System EM effects stress based on defined Dominant EM effects
- The selected margin depends on system function criticality and failure cost. Quantitatively, it also depends on stress and strength uncertainties
## TECHNICAL BASIS
### PENETRATING STRESS VS. FREQUENCY

<table>
<thead>
<tr>
<th>Penetration Category</th>
<th>Frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductive (TEM)</td>
<td>Low kHz to MHz: Most important at lower frequencies (\text{Varies as } 1/\sqrt{f})</td>
</tr>
<tr>
<td></td>
<td>Intermediate MHz to GHz: N/A</td>
</tr>
<tr>
<td></td>
<td>High GHz and Up: N/A</td>
</tr>
<tr>
<td>Aperture</td>
<td>Most important at higher frequencies (\text{Increases with } f)</td>
</tr>
<tr>
<td>Deliberate Antenna</td>
<td>In-band and out-of-band dependence</td>
</tr>
<tr>
<td>Diffusion</td>
<td>Varies as (\exp(-\sqrt{f}))</td>
</tr>
<tr>
<td></td>
<td>Usually small to negligible for good conductors</td>
</tr>
</tbody>
</table>
OPTIONS FOR ALLOWABLE RESIDUAL LEVELS

TECHNICAL BASIS

- Transient stress burnout
- Rated power (manufacturer-specified)
- Operating signal level
- Normal operating noise level

Increasing residual stress

Decreasing risk
TECHNICAL BASIS
SYSTEM VOLUME AND SURFACE TOPOLOGY (GENERAL)

- Topological levels of protection
  - System Level
  - Subsystem Level
  - Box Level
  - Component Level

Exterior Region $V_0$

Communication Lines

Antenna

System Power

Power Line

Aperture (Doors, Windows, Etc.)

Outer Surface $S_1$
<table>
<thead>
<tr>
<th>Shielding</th>
<th>Filters</th>
<th>Nonlinear devices</th>
<th>Fiber Optics</th>
<th>Other materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightweight materials, continuous metal</td>
<td>Narrow, intermediate, and wide band, low insertion loss Moderate to high current capacity (tens to hundreds of kiloamperes)</td>
<td>Fast switching (nanoseconds to subnanoseconds) Moderate to high current capacity (tens to hundreds of kiloamperes)</td>
<td>Small signal, wide band (hundreds of megahertz to a few gigahertz) (characteristics depend on system functional design)</td>
<td>Dielectric isolation Rugged, weatherproof</td>
</tr>
<tr>
<td>MOVs Sparkgaps Zeners</td>
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</tbody>
</table>
**TECHNICAL BASIS**

**VALIDATION LEVELS (DEGREES)**

- Can tolerate failures/repairable
- High failure rate intolerable
- Low tolerance for failure

Tolerance for failure \( \alpha = \frac{1}{\text{cost of failure}} \)

- No test (use operating experience)
- Single sample test (test one item, assume all others the same)
- Large sample and life-cycle surveillance
<table>
<thead>
<tr>
<th>Relative Test Cost</th>
<th>Highest</th>
<th>Medium</th>
<th>Lowest</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subsystem Level</td>
<td>✔️</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Box Level</td>
<td></td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td>Selected Hardening Topology</td>
<td>Box</td>
<td>Subsystem</td>
<td>System Level</td>
</tr>
</tbody>
</table>

*For medium-to-large size systems with a large number of boxes.*
GENERALIZED PROTECTION APPROACH

- Define system EM effects requirements
- Determine tolerance to system effects
- Identify and prioritize Dominant EM effects
- Develop system topological protection approach
- Design and install protection
- Validate protection
- Maintain over system lifetime
SUMMARY

- Unification of EM effects protection is vital to system reliability and is cost-effective
- Protection and validation technologies exist - no major development required
- Challenge will be to define Dominant EM effects based on system requirements and acceptable costs
- Validation testing requirements are a strong function of the topology selected
- Both military and commercial hardware must be considered