Annual Review: EMP Risk Assessment and Mitigation Prioritization

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5G Infrastructure Resilience

• Electromagnetic Pulse (EMP) attacks have the potential to disrupt and damage electronics throughout our nation’s critical infrastructure, posing a serious risk to that infrastructure. Assessing the risk of such events is extremely challenging due to the complexity of our systems.

• This project addressed the threat of EMP to our nation’s critical infrastructure, which includes our nation’s power grid and mobile communication systems.
Our Approach

• Use uncertainty and randomness as a means of tackling and overcoming complexity for the purpose of mitigation

• This approach differs fundamentally from traditional methods that cannot account for the multi-scale material and geometry complexity and the variabilities and uncertainties inherently present in the EMP problem due to the computational complexities.

• Our goals included both developing this capability and using it to assess EMP effects on the electronics in a 5G communications tower.
Objectives

• Ability to quickly assess and predict impact of an EMP attack on 5G infrastructure
• Ability to help preemptively mitigate effects of such attacks via Characterization, Validation, Simulation & Mitigation

Benefits & Potential Impact

• Critical to CISA
• Accurate risk assessment of EMP attack
• Help increase resilience to EMP attack
• Facilitate mitigation measures
5G Infrastructure
Hybrid Cable & Surge Protection Devices

The internal structure of a hybrid cable.
Hybrid Cable

- Since fiber-optic cable uses light, not electricity, to propagate signals, it does not carry power to remote radios. A power cable must be added to provide the power to these devices: ➔ hybrid cable contains both types in a single sheath.
EMP Waveform

- Initial Focus on E1 Pulse:
  - $V = E_0k(e^{-at} - e^{-bt})$, where
  - $E_0 = 50kV$,
  - $k = 1.3$,
  - $a = 4e7$, and
  - $b = 6e8$

E1-EMP: 50kV/m - 400MHz
E2-EMP: 0.1kV/m - 100kHz-1MHz
E3-EMP: 10V/m - < 1Hz
Cable runs from just below top of tower down to outside of the base station.
Accomplishments

• Extraction of Hybrid cable parameters as a function of frequency (code)
• Transient simulation of hybrid cable (code)
• Implement TVS device into simulator
• Implement MOV device into simulator
• Preliminary stochastic analysis of system
Transient Voltage Suppressors (TVS)

Circuit Model

Jim Lepkowski, Evaluating TVS Protection Circuits with SPICE, Power Electronics Technology January 2006
Modeling MOVs

Nonlinear Resistors

![CIRI Critical Infrastructure Resilience Institute](ciri.illinois.edu)

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<th>V(kV)</th>
<th>Resistance (kohms)</th>
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Nonlinear Resistors:

\[ L_0 = 0.00029 \text{ mH} \]
\[ L_1 = 0.02175 \text{ mH} \]
\[ R_1 = 145 \Omega \]
\[ R_2 = 94.26 \Omega \]

\[ C = 6.9 \times 10^{-5} \text{ \mu F} \]
The LIM platform is optimal for accurate simulation of signals in hybrid cable.

**Features**
- Rapid transient analysis
- Transistor-level simulations
- Frequency-dependent components
- Fast transmission-line analysis
- Large netlists
- Time step control
- Tunable accuracy and speed
- Chip, package or board

**Applications**
- Power Delivery Networks
- IR Drop Analysis
- Analog/Mixed Signal Simulation
- Macromodel Analysis
- IC Verification
- High-Speed Link Design
LIM Results

Hybrid Cable – No Suppression

Hybrid Cable – With Suppression
High-Speed Link Simulation
Initial Stochastic Results

- Varied Incident Angle of EMP
  - Θ and φ
- Evaluated at stochastic collocation points on sparse grid
  - Final Metric: Signal Eye Width
- Adjusted shielding level
  - 5dB, 10db and 20dB
- Created interpolant function from results and generated probability distribution function
Activities Remaining

• Validation & model enhancement of hybrid cable, arresters
• Behavioral modeling of PCB
• Refine EM coupling solution for surface currents
• Mitigation study via stochastic analysis ➔ LIM Enhancement
Hybrid Cable Model Validation

- Measure Cable S Parameters (VNA)
- Optimize with field solver
- Assess frequency dependence
- Perform iteration
PCB Modeling

- Identify points of entry (e.g. PDN)
- Reduce complexity via behavioral modeling
- Macromodels via MOR
- IBIS model implementation
- X parameters
Accurate Computation of the Surface Currents on Hybrid Cable over Lossy Ground Illuminated by EMP Waves

- **Motivation**
  - Hybrid cables with lean to an 5G RF tower is a multi-scale geometry. Finite element approximation of multi-scale geometries are prone to ill-conditioning over EMP frequency spectra range. Numerical experiments show that US Government code SENTRi and ANSYS’ HFSS break down at EMP frequencies.

- **Proposal and Implementation**
  - We are developing a customized code that utilizes the mixed potential integral equation together with graph-based loop-tree decomposition technique, for the accurate computation of the external currents on the shielding conductor of the hybrid cables under EMP excitation at the whole EMP spectra range.
  - Lossy ground effects will be included.
Summary

- Proof of concept established
- Electromagnetic extraction and circuit simulation are key components
- FEM field solver
- LIM simulation engine
- Validation & refining of model will provide robust tool for mitigation