Models to Enable System-level Electrostatic Discharge Analysis
Pls: E. Rosenbaum / M. Raginsky; Team members: Z. Chen, J. Xiong, A. Battini; Project Year funding $63,902

Project Definition

- System-level ESD reliability is achieved through an inefficient process of trial & error
- Simulation has been proposed as a solution
- Roadblock: ESD models of the system components are needed but are not provided
- Solution: Develop a methodology to learn accurate and computationally-efficient ESD models

Results and Significance

- The most prognostic feature for soft failure probability is pre-charge voltage (not $I_{\text{peak}}$ or $t_{\text{rise}}$)
  - Stochastic nature of soft failures may not be (primarily) due to stochastic nature of discharge waveform
- RNN training has a long-term memory problem if the circuit has a settling time $> 100x$ the necessary sampling rate for the expected stimuli (10x for GRU)
  - Inclusion of package inductance in ESD circuit model causes problems

Progress (since Oct. 2017)

- J. Xiong et al., “Enhanced IC modeling methodology for system-level ESD simulation,” accepted for 2018 EOS/ESD Symp.
- On track toward milestones
- Deliverable: Code for learning a multi-port I-V model

Future Outlook

- Verify that the newly-developed hybrid EM-circuit ESD simulation methodology correctly identifies soft failure hazards in a design
- Address the long-term memory problem for RNN-models of component ESD response
- Additional applications of RNN for circuit modeling

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Air Discharge Modeling

- Feature vector $x$: $(V_{pre}, \phi)$
  - $\phi$ denotes humidity
- Variable vector $y$: $(I_{peak}, t_r)$
- The posterior distribution is sampled using the Metropolis-Hastings algorithm (a Markov chain Monte Carlo method)

- Model validation
- 55 measured points, not included in training data
- 10,000 simulated points

$f_{I_{peak}|V_{pre},\phi}(u | 8, 40)$

$V_{pre} = 15 \text{ kV}$
$\phi = 32\%$
PDN-Aware I-V Models

![Diagram of PDN-Aware I-V Models](image)

- Behavioral model (PDN#1)
- Exact model (PDN#1)
- Behavioral model (PDN#2)
- Exact model (PDN#2)

Quasi-static Current [\(\text{A}\)] vs. Quasi-static Voltage [\(\text{V}\)]
RNN-based Transient Model

<table>
<thead>
<tr>
<th>Case</th>
<th>Stimuli</th>
<th>Voltage</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean RE</td>
<td>Max AE</td>
</tr>
<tr>
<td>Power</td>
<td>Random</td>
<td>1.34%</td>
<td>0.74 V</td>
</tr>
<tr>
<td>Off</td>
<td>IEC</td>
<td>17.3%</td>
<td>4.1 V</td>
</tr>
<tr>
<td>Power</td>
<td>Random</td>
<td>3.62%</td>
<td>1.54 V</td>
</tr>
<tr>
<td>On</td>
<td>IEC</td>
<td>9.96%</td>
<td>3.86 V</td>
</tr>
</tbody>
</table>

- Ordinary RNN was replaced by a gated recurrent unit (GRU) network for better handling of long-term memory
- Results (in Table) still not ideal; work continues
In-package ESD Noise Coupling

Package Model

Die model (behavioral)

(a) Pin Model
- Bus1
- Bus2
- Bus3

(b) Partial ESD Network Example
- VDDIO
- VDD
- VSS

Behavioral Model
- I/O protection
- Rail Clamp
- I/O pin
- VDD pin
- VSS pin

Hybrid EM-circuit simulation results

Distant pin has induced glitches if it’s near return path.