Comparison of extraction methods to build a radiated emission model of ICs (ICEM-RE): pros and cons

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September 8, 2017
• Intro: state of the art about emission modelling of IC

• ICEM-RE modeling approaches:
  1. Extraction from ICEM-CE (Combined ICEM model)
  2. Direct extraction method from NFS measurements

• Conclusion: Pros & Cons
State of the art about IC emission modeling

  • 2016 : C. Ghfiri, A. Durier, A. Boyer, S. Ben Dhia, C. Marot “Construction of a Integrated Circuit emission model of a FPGA” APEMC 2016, Shenzhen, China
  • 2010 : K.R. Aravind Britto, R. Dhanasekaran, R. Vimala, K. Baskaran; "EMC analysis of PCB using ICEM model"; 2010 IEEE International Conference on EMC, Ramanathapuram, India
  • 2008 : C Labussière-Dorgan; S Bendhia; E Sicard; J Tao; H J Quaresma; C Lochot; B Vrignon; “Modeling the Electromagnetic Emission of a Microcontroller Using a Single Model”; IEEE Transactions on EMC, 2008, Volume: 50
  • 2006 : T. Steinbecke, D. Hesidenz, E. Miersch “EMI modeling and simulation in the IC design process”; EMC-Zurich; 17th International Zurich Symposium on EMC
  • 2006 : F Lafon, F De Daran; “Analyse de risque au niveau système par l'exploitation du modèle ICEM”; Colloque CEM06, At Saint Malo, France
  • 2004 : F Lafon, O Maurice, F De Daran, C Lochot, S Calvet; "Exploitation of the ICEM model in an automotive application" EMC COMPO 2004, Angers, France
  • 2004 : M. Ramdani; J.-L. Levant; R. Perdriaux "ICEM model extraction: a case study" International Symposium on EMC, 2004
  • 2002 : JL Levant; M Ramdani; R Perdriaux; “Power- Supply Network Modeling”; 3rd International Workshop on EMC of IC, Nov 2002, Toulouse, France

One block for one specific issue
• Each block is built according to a specific extraction method
• "Matriochkas approach"
• Proven / predicted approach

• Based on NFS measurements
• Quick modeling process (full automated)
• Usable for far field prediction

@ A Ramanujan, F Lafon, P Fernandez-Lopez; “Radiated Emissions Modelling From Near-Field Data – Toward International Standards”, APEMC 2015, Taipei – Taiwan
State of the art about IC emission modeling

• State of the art:
  • Two models:
    ➢ 2x workflows (measurement methods)
    ➢ 2x software (model format, license)
    ➢ 2x times / costs

• Proposal: Re-use ICEM-CE to build ICEM-RE
  • Only one modeling process
  • Combined all advantage of two approaches
  • Only one model / simulation tools for both conducted and radiated emission analyse
  • Industrially compatible with costs and delays

@ "Proposal for combined conducted and radiated emission modelling for Integrated Circuit", S. Serpaud, C. Ghfiri, A. Boyer, A. Durier; EMC-Compo 2017 workshop; Russia, Saint-Petersburg; July 6, 2017
• Intro: state of the art about emission modelling of IC

• ICEM-RE modeling approaches
  1. Extraction from ICEM-CE (Combined ICEM model)
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• Conclusion: Pros & Cons
• **DUT : Spartan 6 family of Xilinx**

<table>
<thead>
<tr>
<th>Activity rate (%) LUT used</th>
<th>Configurations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With periodical switching</td>
</tr>
<tr>
<td></td>
<td>of two I/Os at 8 MHz (T9 and C16)</td>
</tr>
<tr>
<td>20 %</td>
<td>“Config 20% IOon”</td>
</tr>
<tr>
<td>40 %</td>
<td>“Config 40% IOon”</td>
</tr>
<tr>
<td>90 %</td>
<td>“Config 90% IOon”</td>
</tr>
</tbody>
</table>
ICEM-RE modelling approach from ICEM-CE

- ICEM-RE model from ICEM-CE model
- **ICEM-CE**: "Methodology of modelling of the internal activity of a FPGA for conducted emission prediction purpose" C. Ghfiri\(^1,2,3\), A. Boyer\(^2,3\), A. Durier\(^1\), S. Ben Dhia\(^2,3\); EMC-Compo2017, Saint Petersburg; Russia

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**Simplified PDN core model**

PDN IO  

cia IO  

**IA core (CLB+CLK+PLL+RAM)**

\[ P_{\text{dyn\_avg}} = \frac{F_C}{2} \sum_{i=1}^{N} \alpha(i) q_L(i) \cdot V_{DD} \]

\[ Q_L = \sum_{i=1}^{N} \alpha(i) q_L(i) = I_{\text{avg}} \cdot T_C \]

\[ I_{\text{max}} = 2 \cdot I_{\text{avg}} \cdot \frac{T_C}{\tau} \]
ICEM-RE modelling approach from ICEM-CE

- ICEM-RE model from ICEM-CE model
  - ICEM-CE: “Methodology of modelling of the internal activity of a FPGA for conducted emission prediction purpose” C. Ghfiri\textsuperscript{1,2,3}, A. Boyer\textsuperscript{2,3}, A. Durier\textsuperscript{1}, S. Ben Dhia\textsuperscript{2,3}; EMC-Compo2017, Saint Petersburg; Russia
  - EAN: Electrical Antenna Network
**Physical PDN structure of FPGA – from XRAY**

**Two-layer plastic BGA 256 (FT256) package**

**Package structure of FPGA from X-Ray**

Top Layer

Bottom Layer

Xray from Continental
• Physical PDN structure of FPGA – from XRAY & from pinout

EAN bloc from X-Ray of package (235 dipoles)

EAN bloc from Pinout of package (115 dipoles)
ICEM-RE modelling approach from ICEM-CE

• ICEM-RE = EAN + ICEM-CE of FPGA

Simulation done on IC-EMC software (www.ic-emc.org)
ICEM-RE modelling approach from ICEM-CE

• Extraction EAN bloc – **C16 IO Activity @8MHz (90%LUT with IO config)**

- **Hx**
  - $H_{x_{\text{max}}} = -22.7 \text{dB} \mu \text{A/m}$

- **Hy**
  - $H_{y_{\text{max}}} = -23.3 \text{dB} \mu \text{A/m}$

- **Hz**
  - $H_{z_{\text{max}}} = -22.2 \text{dB} \mu \text{A/m}$

NFS measurement

Simulation EAN extracted from Pinout

Simulation EAN extracted from Xray

Simulation done on IC-EMC software (www.ic-emc.org)
ICEM-RE modelling approach from ICEM-CE

- Extraction EAN bloc – Core Activity @16MHz (90% LUT without IO config)

NFS measurement

Simulation EAN extracted from Pinout

Simulation EAN extracted from Xray

No simulation result (simulation tool limitation)

Simulation done on IC-EMC software (www.ic-emc.org)
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• Conclusion : Pros & Cons
ICEM-RE extraction method from NFS measurement

- Direct extraction ICEM-RE from NFS measurement

Core Activity @16MHz (90% LUT without IO config)

**NFS measurement**

**Simulation of one dipôle**

**Magnitude**

**Phase**

### Dipole Measurement Table

<table>
<thead>
<tr>
<th>Type</th>
<th>Hx Max</th>
<th>Hy Max</th>
<th>Hz Max</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-31dBµA/m</td>
<td>-31.5dBµA/m</td>
<td>-32.7dBµA/m</td>
</tr>
</tbody>
</table>

### Simulation Diagrams

- **Hx**
  - Dipole: 0, Height: 0.65 mm, |Htan|: 35.9 [dbA/m], I(f): 623 [µA], I(t): 6.1 [mA], Type: Core
- Dipole: 1, Height: 0.65 mm, |Htan|: 37.5 [dbA/m], I(f): 518 [µA], I(t): 5 [mA], Type: Core
- Dipole: 2, Height: 1.15 mm, |Htan|: 31 [dbA/m], I(f): 418 [µA], I(t): 3.1 [mA], Type: IO
- Dipole: 3, Height: 1.15 mm, |Htan|: 31 [dbA/m], I(f): 569 [µA], I(t): 5.5 [mA], Type: IO
- Dipole: 4, Height: 1.15 mm, |Htan|: 35 [dbA/m], I(f): 359 [µA], I(t): 3.5 [mA], Type: IO
- Dipole: 5, Height: 0.65 mm, |Htan|: 38.2 [dbA/m], I(f): 478 [µA], I(t): 4.6 [mA], Type: Core
- Dipole: 6, Height: 0.65 mm, |Htan|: 36.6 [dbA/m], I(f): 575 [µA], I(t): 5.6 [mA], Type: Core

- **Hy**
  - Dipole: A, Height: 0.65 mm, |Htan|: -38 [dbA/m], I(f): 549 [µA], I(t): 4.7 [mA], Type: Core
  - Dipole: B, Height: 1.15 mm, |Htan|: -31.6 [dbA/m], I(f): 531 [µA], I(t): 5.2 [mA], Type: Core
  - Dipole: C, Height: 0.65 mm, |Htan|: -38.5 [dbA/m], I(f): 462 [µA], I(t): 4.5 [mA], Type: IO
  - Dipole: D, Height: 0.65 mm, |Htan|: -39/-41 [dbA/m], I(f): 550 [µA], I(t): 4.7/3.3 [mA], Type: IO
  - Dipole: E, Height: 0.65 mm, |Htan|: -35.2 [dbA/m], I(f): 675.5 [µA], I(t): 6.6/4 [mA], Type: IO
  - Dipole: a, Height: 1.15 mm, |Htan|: -39 [dbA/m], I(f): 226.5 [µA], I(t): 2.2 [mA], Type: Core
  - Dipole: b, Height: 1.15 mm, |Htan|: -32.2 [dbA/m], I(f): 648.4 [µA], I(t): 4.8 [mA], Type: Core
  - Dipole: c, Height: 0.65 mm, |Htan|: -41.8 [dbA/m], I(f): 316 [µA], I(t): 3.1 [mA], Type: Core
  - Dipole: d, Height: 0.65 mm, |Htan|: -39 [dbA/m], I(f): 550 [µA], I(t): 4.7 [mA], Type: IO
  - Dipole: e, Height: 0.65 mm, |Htan|: -39/-41 [dbA/m], I(f): 550 [µA], I(t): 4.7/3.3 [mA], Type: Core
ICEM-RE extraction approach

- EAN block Extraction – from NFS Measurement

Physical package structure of FPGA from X-Ray

EAN bloc from NFS Measurement (17 dipoles)
FPGA Activity analyse - 40% without IO
NFSev on FPGA - Hz component

Localization of picked point:
• Radiated activity (40% without IO configuration)

<table>
<thead>
<tr>
<th>Activity type</th>
<th>Frequency domain parameters</th>
<th>Time domain parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[H\text{tang}]_{\text{max}} \quad [\text{dBµA/m}]</td>
<td>[A_{\text{f,max}}] \quad [\text{mA}]</td>
</tr>
<tr>
<td>Core_90%</td>
<td>98.5</td>
<td>1.7</td>
</tr>
<tr>
<td>Core_40%</td>
<td>92.8</td>
<td>0.881</td>
</tr>
<tr>
<td>Core_20%</td>
<td>89.1</td>
<td>0.575</td>
</tr>
<tr>
<td>Input</td>
<td>87.6</td>
<td>0.484</td>
</tr>
<tr>
<td>Output</td>
<td>97.8</td>
<td>1.5</td>
</tr>
</tbody>
</table>

* Value compute from equation (2) with \( h=1.15\text{mm}; R=1.825\text{mm} \)

Radiated Dipole Equation

\[
H_{\text{tang}} = \frac{I}{2\pi} \left[ \frac{t + 2h}{R(R + t + 2h)} \right] \quad (3)
\]

\[
I = 2\pi.H_{\text{tang}} \left[ \frac{R(R + t + 2h)}{t + 2h} \right] \quad (4)
\]

Assume:

\[ t << h, \quad t << R, \quad h \text{ and } R << \lambda \]
ICEM- RE extraction method from NFS measurement

- Direct extraction ICEM-RE from NFS measurement

Core Activity @16MHz (90% LUT without IO config)

Simulation done on IC-EMC software (www.ic-emc.org)
ICEM- RE extraction method from NFS measurement

- Direct extraction ICEM-RE from NFS measurement – Hz field component
  Core Activity @16MHz (90% LUT without IO config)

Magnitude Measurement

Vector Measurement

Simulation

Simulation done on IC-EMC software (www.ic-emc.org)
## Conclusion – pros & cons

### ICEM-RE extraction method: Two complementary approaches:

<table>
<thead>
<tr>
<th>ICEM-RE from ICEM-CE</th>
<th>ICEM-RE from NFSe</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Predictive approach</td>
<td>+ Low cost (NFSe measurement only)</td>
</tr>
<tr>
<td>+ Close to the physical structure</td>
<td>+ Quick extraction method</td>
</tr>
<tr>
<td>+ Close to the application</td>
<td>+ Close to the application</td>
</tr>
<tr>
<td>+ Available for Far Field prediction</td>
<td>+ Available for Far Field prediction</td>
</tr>
<tr>
<td>- Expensive cost method (means &amp; time)</td>
<td>- Based on measurement</td>
</tr>
<tr>
<td>- Long time to develop</td>
<td>- Not predictive approach</td>
</tr>
<tr>
<td>- Complex model (PDN)</td>
<td>- Manual approach (→ automate)</td>
</tr>
<tr>
<td>- Limited on the complex device (BGA)</td>
<td>- Limited for wide frequency range</td>
</tr>
</tbody>
</table>
Thank for your attention

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