EMC Simulation in Modern Electronics
Agenda

Introduction

Early Design Stage
- Simple differential lines

Workflow for Emission

Late Design Stage
- Realistic differential lines
- Enclosure simulation
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EMC Simulation in the Design Process

EMC at all Stages of the Design Process

- multiple troubleshooting iterations
- high effort and costs to correct
- delayed time to market

![Cost of change over time diagram](chart.png)
EMC Simulation in the Design Process

Design stage

• can accompany the design process and be employed at an early design stage
• can give answers to fundamental “what if” questions
• can deliver output not accessible by measurements
• can be performed without a prototype

Troubleshoot

• can help to understand behavior of the device
• allows to test mitigation strategies
• not a competitor to measurements, both should be used complementary
EMC Simulation in the Design Process

### Measurement
- Used and relied on for over 50 years
- Measurement devices are physical objects
- Ideal conditions are difficult to produce
- Information about the products is not necessary

### Simulation
- Rarely used in EMC industry until 6-7 years ago
- Measurement devices can be infinitesimally small
- Ideal conditions are easy to produce (non-ideal is difficult)
- Only as accurate as the input provided

Source: Scott Piper
Simulation vs. Measurement

EM emissions induced by a DC/DC power converter.
G. Chiappori, S Baranowski, O Cohin,
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Differential Lines
Differential Traces

Trace width 0.8 mm
Trace separation 0.8 mm

FR-4 substrate: Eps_r 4.3
Substrate thickness: 0.4 mm
Single Ended Line Impedance

49.93 Ohm

46.82 Ohm
Differential Line Impedance

$Z_d = 2 \times Z_0$

$Z_c = Z_0 / 2$

Derived for uncoupled lines!
Differential Line Impedance

Derived for uncoupled lines!

1.6 ... 4.2 mm

1D Results\Line Impedances

<table>
<thead>
<tr>
<th>Impedance / Ohm</th>
<th>distance / mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>20</td>
</tr>
<tr>
<td>2.0</td>
<td>30</td>
</tr>
<tr>
<td>2.5</td>
<td>40</td>
</tr>
<tr>
<td>3.0</td>
<td>50</td>
</tr>
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<td>3.5</td>
<td>60</td>
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<td>4.0</td>
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<tr>
<td>4.5</td>
<td>80</td>
</tr>
<tr>
<td>5.0</td>
<td>90</td>
</tr>
</tbody>
</table>

comm

diff
S Parameter
Radiated E-Field

E Field at 3m distance for 1V broadband

![Graph showing the radiated E-field at 3m distance for 1V broadband. The graph plots the probe value in dBuV against frequency in GHz. The x-axis ranges from 0.03 to 2 GHz, while the y-axis ranges from -20 to 100 dBuV. There is a red line indicating the ideal lines.](image-url)
Substrate Size

10 mm

60 mm

Minor effect on S-Parameter
Substrate Size - Radiation

10 mm

60 mm

18 dB at 1 GHz
Substrate Position

Transmission only slightly affected
Substrate Position

Common mode become excited
Substrate Position - Radiation

20 dB @ 1 GHz - Edge 1 mm and 10 mm
Meander Y-Direction

2.5 mm

15 mm

Effect clearly visible in transmission
Meander Y-Direction - Radiation

2.5 mm

15 mm

40 dB @ 1 GHz
Summary Differential Lines

Early Design stage

- can give answers to fundamental “what if” questions
- different solver levels
  - Analytical
  - 2D Field solver
  - 3D Field solver

Differential Lines Study

- S Parameter difficult to predict radiation
- use to study trade offs
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Workflow for Emission Simulation

Model Geometry → 3D EM Simulation → Circuit Setup → Circuit Simulation
Workflow for Emission Simulation

Model Geometry ↔ 3D EM Simulation ↔ Circuit Setup ↔ Circuit Simulation
Combine Results

Combine results

- Calculate 3D field distribution considering an attached circuit
- Apply linear superposition in post-processing

3D EM solver calculates field pattern

- Each port excited separately, other ports passive
Combine Results

AC Analysis calculates the voltages/currents at each pin.
- This excitation is applied to the field patterns of all ports

Field results at the speed of a circuit simulation
- No 3D solver run, just post processing
- Even for highly complex models just a few minutes
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Demonstrator

EMC Simulation in the Design Flow of Modern Electronics

Jens Krämer
Pietro Luzzi
Real PCB Differential Lines

Good

Bad
Measurement

Max from hor & vert, turntable at 0°, 90°, 180°, 270°
Results Comparison

[Graphs showing measurement and broadband 1V simulation]

- Measurement
- Broadband 1V Simulation

Red line: bad
Blue line: good
Results Comparison

Rectangular Pulse, 250 MHz, 100 ps rise, 1.2 V

Good  Bad
Emission from PDN

Port at the PDN of the driver IC.
Emission from PDN

Port at the PDN of the driver IC.

Excite PDN of the driver IC with the current spectrum.
Emission from PDN

Just Traces

Traces and PDN
## Summary Real Differential Lines

### Radiation Sources
- Current on the signal path
  - Traces and Return current path
  - Emission from the power delivery network

### Matching Simulation and Measurement
- 3D solver can model all effects
- Some key effects missing in the model

### Correct Modeling
- Use another solver or mesh
- Boundary setting
- Materials
Enclosure

PCB placed into an enclosure and measured
Shielding Effectiveness

Emission Measurement

Shielding Effectiveness

$S.E = 20 \log \frac{E_{\text{without shield}}}{E_{\text{with shield}}}$
Enclosure and Full PCB

Full PCB and enclosure model
Enclosure and Full PCB

Enclosure Measurement

Enclosure Simulation
Enclosure and Simple PCB

Simple PCB
- 840k mesh cells
- 1 ports, -50 dB accuracy
- 1 Nvidia Kepler 20 GPU’s
- Run time: 0h7m40s

Full PCB
- 23meg mesh cells
- 3 ports, -50 dB accuracy
- 4 Nvidia Kepler 20 GPU’s
- Run time: 6h17m38s
Enclosure and Simple PCB
Enclosure and Simple PCB

![Graph showing peak E-field from probes (dBuV/m) vs. frequency (MHz) for different scenarios: Enclosure, Enclosure and Screws, and PCB. Red line for PCB shows higher E-field than the other two scenarios.]

Added Screws
Contact Resistance

Effect of a finite contact resistance
Enclosure and Simple PCB

Shrinked and Rotated PCB
Summary Enclosure

Full Model

- It is possible to model full PCB with real enclosure
- Pulsed driver only excites discrete frequencies

Simplified Source

- Modeling excitation with by simplified source speeds up simulation
- Allows to study broadband behavior and enclosure resonances
- Shielding effectiveness depends on source and placement
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