Computational Electromagnetics for Electromagnetic Compatibility/ Signal Integrity Analysis

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Motivation of the Talk

- Number of chapters wrote to me and asked to talk on EMC Modeling, i.e.
- Status of the numerical techniques
- Applicability
- Problems vs methods
- Whether the simulation can solve 100% EMC problems? If not why still develop and use it?
Outline

- Overview of Computational Electromagnetic Modelling
- Few Common Numerical Methods for EMC Modeling
  - MoM;
  - FDTD;
  - FEM.
- Modelling of Multilayered IC Packages
  - Motivation
  - Method Overview
  - Recent Development
- Outlook and Summary
- Simulation Challenges
1 Overview of Computational Electromagnetic Modelling
The Needs for EMC Simulation

- EMC is necessity
  - to guarantee no or least EM disturbance to the environment and to guarantee a correct work in environment EM disturbance
  - to have a robust design in normal environment

- The EMC becomes critical and more difficult
  - logic speed increase (frequency increase, transition time decrease) => high frequency emission increase
  - IC technologies evolution (size decrease, node capacitors decrease, digital level decrease, integration increase) => noise margin decreases and more sensitive to HF disturbances
  - power electronics evolution (digital control, switching frequency and power increase) makes harder standard EMC emission compliance and design robustness

- The EMC problems can be diversified
  - at system level: intersystems EMC and intrasystems EMC
  - at electronic board level
  - at chip/component level

- EMC must be take into account at the beginning of the design

- EMC modeling and simulation tools is required
  - to help system engineers in the architecture definition
  - to help electronic engineers in the product design with EMC consideration
  - to help industrial companies for reducing the time and cost of retrofit
Maxwell Equations

\[ \text{curl } H = \frac{4\pi}{c} j + \frac{1}{c} \frac{\partial D}{\partial t} \]

\[ \text{curl } E = -\frac{1}{c} \frac{\partial B}{\partial t} \]

\[ \text{div } D = 4\pi \rho \]

\[ \text{div } B = 0 \]

... Light is an electromagnetic wave governed by the interaction of electric and magnetic fields.

James Clerk Maxwell (1831-1879)
Brief History of Electromagnetic Computation

- 1950s  Structural analysis
- 1965  A. M. Winslow (first EE application)
- 1966  Yee, Finite Differential Time Domain (FDTD)
- 1969  P. P. Silvester (waveguide analysis)
- 1970  Johns & Beurle (Transmission Line Method)
- 1974  K. K. Mei (unimoment method for scattering and antenna analysis)
- 1974  A. Ruehli (PEEC)
- 1980  J. C. Nedelec (vector elements)
- 1982  S. P. Marin (combined with boundary integral equations for scattering analysis)
- 1985-  Extensive developments for EM problems

J. M. Jin, FEM for EM, IEEE Press
Recent Progress

- Higher-order vector elements
- Hybridization with boundary integral method
- Hybridization with asymptotic methods
- Time-domain finite element method
- Fast multipole method
- Multilevel Fast Multipole Method
- Fast High Order Method
Computational Electromagnetic Methodologies

CEM

Time Domain
- PDE
  - FDTD
  - TLM
  - IETD

Frequency Domain
- IE
  - FDM
  - PEEC

Low Frequency
- FEM

High Frequency
- GO
- PO

Hybrid Methods
- CGFFT
- UTD
- PTD
- UAT
- FMM
- AIM
- SBR

• **Analytical method:**
  – only available for problems with a high degree of symmetry.

• **Numerical Methods (low frequency methods)**
  – **Integral equation** based methods: Method of Moments (MoM), PEEC, Fast Multipole Method (FMM), etc.
  – **Differential equation** based methods: finite element method (FEM), finite difference method (FDTD), FIT, TLM, FVTD, etc.

• **Asymptotic Approaches (high frequency methods)**
  – Geometric Optics (GO), geometric theory of diffraction (GTD)
  – Physical optics (PO), physical theory of diffraction (PTD)

• **Hybrid Methods**
  – Numerical method cum numerical method: FEM-MoM
  – Numerical method cum asymptotic method: MoM-PO/GTD/PTD

2 Review of Numerical Methods

Method of Moments (MoM)
Method of Moments (MoM)

Method of moments (MoM) transforms the governing integral equation of a given problem, by weighted residual techniques, into a matrix equation to be solved numerically on a computer.

Illustration of the procedures of MoM:

>Consider the inhomogeneous equation (integral equation)<

\[ \mathcal{L} \phi = f \]

known function (excitation)

Linear Operator (integral) \[\hat{n} \times \mathbf{E}^i(r) = \hat{n} \times \int_{S} \left[ j \omega \mu \mathbf{J}_s G(r,r') + \frac{1}{j \omega \varepsilon} (\nabla'_s \cdot \mathbf{J}_s) \nabla' G \right] ds' \]

Known (Incident field) Green’s function Unknown (surface current) \( r \in S \)
Method of Moments (MoM)

Illustration of the procedures of MoM (Cont’d):

- **Discretization**
  - Meshing the structure into elements
  - Expanding the unknown function by using basis functions

  \[ \phi = \sum_{n=1}^{N} \alpha_n \psi_n \]

  The original integral equation becomes:

  \[ \sum_{n=1}^{N} \alpha_n \mathcal{L} \psi_n = f \]

- **Testing (conversion)**

  Choose a set of testing functions, take the inner product, then convert it into a matrix equation

  \[ \sum_{n=1}^{N} \alpha_n \langle w_n, \mathcal{L} \psi_n \rangle = \langle w_n, f \rangle \rightarrow [Z] \{ \alpha \} = \{ b \} \]

- **Solution & Post-Processing:**

  Solve the matrix equation for the unknown currents; Calculate desired quantities.
**Method of Moments (MoM)**

**Integral Equations** for a given electromagnetic problem are formulated based on the equivalence principle (alternatively on Green’s identity)

- **Surface Integral Equation**
  - Based on *surface equivalence theorem*: Fields outside an imaginary closed surface can be determined by placing over the surface, suitable electric and magnetic currents that satisfy the boundary conditions.
  - Suitable for impenetrable (PEC) body & homogeneous media

- **Volume Integral Equation**
  - Based on *volume equivalence theorem*: Replace inhomogeneity of an object by equivalent volume electric and magnetic currents that radiate in background medium.
  - Suitable for penetrable (inhomogeneous) media

**Basis functions**
- Entire-domain basis function (regular domain)
- Sub-domain basis function (complicated and arbitrary domain)
  - Examples ---
    - Pulse, roof-top, triangular, hexahedron and tetrahedron)
MOM for Simulation of EM Susceptibility

**Incident Field**

**Coupling Algorithm**

**MOM simulation**

**Equivalent Circuit**

**Surface current**

**Equi Impedance**

**Equi Current**

---

MOM for Simulation of EM Susceptibility

- Multi-layered PCB analysis with SPICE
- Ambient EM interference: *harmonic plane wave*

---

The basic concept of fast algorithms is to decompose the MoM matrix into near- and far-interaction components. To reduce the memory requirement for matrix storage and accelerate matrix-vector multiplication, typical fast algorithms include:

- **(ML)FMM** [(multi-level) fast multipole method],
- **CG-FFT** (Conjugate gradient fast fourier transform),
- **AIM** (adaptive integral method)

2-D representation of the procedures of the AIM algorithm:

1. Project panel current density onto grid
2. Compute potentials using FFT
3. Interpolate grid potentials onto panels
4. Compute near zone interactions directly
Method of Moments: Fast Algorithm

FMM & MLFMM (fast multipole)

One-level interaction \((N^2)\) among current elements

MoM : \(Z \cdot \alpha = b \sim O(N^2)\)

A multilevel tree structure showing the interaction among the current elements via the aggregation & disaggregation procedure

Connection between ‘hubs’

FMM : \( (Z_{NN} + V^+ T V) \alpha = b \sim O(N \log N)\)

Interaction from low-level to upper level ‘hub’

Interaction from upper-level ‘hub’ to low-level (elements)

Method of Moments: Fast Algorithm

Computation Cost (CPU time & memory requirements)

Conventional Method of Moments

- $O(N^2)$ memory requirement for matrix storage & $O(N^3)$ operations for direct solution method
- $O(N_{iter}N^2)$ operations for iterative solver

Comparison of CPU time and memory usage between conventional MoM and Fast algorithm

Significant reduction in CPU time and memory usage motivate the development of fast algorithm

[Ref.] J. M. Jin, Finite Element Method in Electromagnetics, 2nd ed. Wiley Interscience
Method of Moments (MoM)

- MOM is strong in solving open domain problems involving impenetrable (PEC) or homogeneous objects, and it has been successfully applied to closed problems such as waveguides and cavities as well.

- MoM is applicable to many EM-related application areas:
  - Electrostatic problems,
  - Wire antennas and scatterers,
  - Scattering and radiation from bodies of revolution or bodies of arbitrary shape,
  - Transmission lines,
  - Aperture problems,
  - Biomedical problems.
Method of Moments (MoM)

Commercial Software

- Numerical Electromagnetic Code (NEC)
  - Developed at the Lawrence Livermore National Laboratory
  - Frequency domain antenna modeling code for wire & surface structures

- FEKO
  - EMC analysis, antenna design, microstrip antennas and circuits, dielectric media, scattering analysis, etc.

- IE3D
  - MMICs, RFICs, LTCC circuits, microwave/millimeter-wave circuits, IC interconnects and packages, patch/wire antennas, and other RF/wireless antennas

... ...
Applications: Aviation industry

Method: MoM with FMM

Solver developed at IHPC, Singapore

Parallel Fast Integral Equation Simulation Method

Packaging Structure

Simulation Time vs Number of Processors
Review of Numerical Methods

Finite-Difference Time-Domain Method (FDTD)
Finite-Difference Time-Domain Method (FDTD)

- Finite Difference Time-Domain (FDTD) method, first introduced by K.S. Yee in 1966, and later developed by Taflove and others, is a direct solution of Maxwell’s Time-dependent curl equations.
- It is a robust, easy-to-understand, easy-to-implement techniques. It is one of the most popular time-domain method for solving EM problems.

\[
\begin{align*}
\nabla \times E &= -\mu \frac{\partial H}{\partial t} \\
\nabla \times H &= \sigma E + \varepsilon \frac{\partial E}{\partial t}
\end{align*}
\]

\[
H_x \big|^{n+\frac{1}{2}}_{(i,j,k)} = H_x \big|^{n-\frac{1}{2}}_{(i,j,k)} - \frac{\Delta t}{\mu} \left( \frac{E_z \big|^{n}_{(i,j+1/2,k)} - E_z \big|^{n}_{(i,j-1/2,k)}}{\Delta y} - \frac{E_y \big|^{n}_{(i,j,k+1/2)} - E_y \big|^{n}_{(i,j,k-1/2)}}{\Delta z} \right)
\]
Finite-Difference Time-Domain Method (FDTD)

- Two interleaved grid points (E & H)
- E & H calculated alternatively at every half time step
- Time step is limited by the Courant’s condition
  \[ \Delta t \leq \frac{1}{\sqrt{1/\Delta x^2 + 1/\Delta y^2 + 1/\Delta z^2}} \]

Yee’s cell in 3-D FDTD simulation.

Strengths of FDTD:
- Easy modeling of complex material configuration
- No matrix inversion involved
- Easily adapted to parallel processing
- Easy to generate broadband data
- Ability to perform both transient and steady state analysis

Weaknesses of FDTD:
- Mesh density is determined by fine geometric details of the problem
- Staircase error for curve structure
- Need to mesh the entire simulation domain
- Need ABC (PML) to truncate unbounded problem domain

Finite-Difference Time-Domain Method (FDTD)

- Recent Development:
  Domain decomposition; conformal FDTD; ADI-FDTD; Pseudo-spectral FDTD

- Other time domain methods
  - FIT (finite integration technique)
  - TLM (transmission line method)
  - FVTD (finite volume time domain)

- Applications of FDTD
  A variety of areas: Wave Propagation, Microwave/Antenna, high-speed electronics, photonics, biomedical problems
Commercial simulators

- CST MicroWave STUDIO®
  - Based on the Finite Integration Technique (FIT)
  - Full-wave electromagnetic field simulation software

- Remcom XFDTD
  - Applications including microwave circuits, antennas, EMC, Scattering, Photonics, Bio-EM, etc.

- ...
Examples for SI, EMI

Before Fix

After Fix

Courteous of CST, Hitachi Data storage
Examples

- Crosstalk is concerned at dense path
- Signal propagation along the lines and interference the adjacent lines

Most coupling in hinge region
Imbalanced layout in this region

Courteous of CST, Hitachi Data storage
2 Review of Numerical Methods

Finite Element Method (FEM)
Finite Element Method (FEM)

**Fundamentals of FEM:**
- FEM is a numerical technique to obtain the approximate solutions to boundary value problems of the mathematical physics.
- The equations in a Finite element (FEM) analysis can be formulated either by a **variational method** (Ritz method) or a **weighted residual** method (Galerkin’s method) [Also used by Method of Moment]

  - **Variational method:** Minimizing an energy functional

    \[
    F = \int_V \left\{ \frac{\mu |H|^2}{2} \epsilon |E|^2 - \frac{J \cdot E}{2 \omega} \right\} dV
    \]

    - Energy stored in magnetic & electric fields
    - Energy dissipated/supplied by conduction currents

**Procedures of FEM Analysis:**
- Discretizing solution regions into finite number of *subregions* or *elements*
- Deriving governing equations (elemental equation) for a typical element
- Assembling of all elements in the solution region to form matrix equation
- Solving the system of equations obtained.
## Finite Element Method (FEM)

### Features:
- Remarkable advantage of FEM is the flexibility in terms of modeling any complicated geometries, distribution of media.
- Good handling of inhomogeneous medium (Each element can have different material property)
- Sparse matrix equation (each element only interacts with elements in its own neighborhood)
- Require to mesh the entire domain (object + background)
- ABC, PML or FE-BI need to be used to truncate the mesh for unbounded problems
- Linear and nonlinear, 2-D/3D problems.
- Widely used in frequency domain

### Recent Development:
- High-order ABC, domain decomposition, high-order elements

### Commercial Software
- Ansoft HFSS
- … …
EMI Simulation Examples

Wire-frame Model of PDA

Monopole Model

Antenna with Mould Bushing

E-field on Casing

Frequency (MHz)

E-field (dBuV/m)

Measured

Simulated
2 Review of Numerical Methods

Comparison of Three CEM Methods
# Comparison of Three CEM Methods

<table>
<thead>
<tr>
<th>Methods</th>
<th>FDTD</th>
<th>MOM</th>
<th>FEM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Principle</strong></td>
<td>Direct solution of Maxwell’s equations</td>
<td>Need Frequency-dependent Green’s function</td>
<td>Variational principle (minimizing energy functional)</td>
</tr>
<tr>
<td><strong>Equation</strong></td>
<td>Differential equation</td>
<td>Integral equation</td>
<td>Differential equation</td>
</tr>
<tr>
<td><strong>Transient or steady state</strong></td>
<td>Time-domain method; Obtain responses over a broad band frequencies by Fourier transform</td>
<td>Frequency domain method -- response at one frequency for one solution of the matrix equation</td>
<td>Frequency domain method -- response at one frequency for one solution of the matrix equation \ Remedy: fast frequency-sweeping approach to obtain response over broad band</td>
</tr>
</tbody>
</table>

## Comparison of Three CEM Methods

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<thead>
<tr>
<th>Methods</th>
<th>FDTD</th>
<th>MOM</th>
<th>FEM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Geometry</strong></td>
<td>Inhomogeneity easy</td>
<td>Inhomogeneity difficult</td>
<td>Nonlinearity, inhomogeneity easy</td>
</tr>
<tr>
<td><strong>materials</strong></td>
<td>Arbitrary shape – staircase error</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Meshing</strong></td>
<td>Entire domain discretized</td>
<td>Normally only surfaces discretized</td>
<td>Entire domain discretized</td>
</tr>
<tr>
<td><strong>Matrix</strong></td>
<td>No matrix equation</td>
<td>Dense matrix</td>
<td>Sparse matrix</td>
</tr>
<tr>
<td><strong>equation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Boundary</strong></td>
<td>Open boundary difficult</td>
<td>Open boundary easy</td>
<td>Open boundary difficult</td>
</tr>
<tr>
<td><strong>treatment</strong></td>
<td>Absorbing boundary needed</td>
<td></td>
<td>Absorbing boundary needed</td>
</tr>
<tr>
<td><strong>Suitable</strong></td>
<td>Most developed time domain method;</td>
<td>More efficient to deal with open domain</td>
<td>More efficient for closed region problems</td>
</tr>
<tr>
<td><strong>problems</strong></td>
<td>applicable to a variety of electromagnetic problems</td>
<td>problems involving impenetrable objects</td>
<td>involving complex geometries &amp; inhomogeneous media objects;</td>
</tr>
</tbody>
</table>

- **FDTD**: Finite Difference Time Domain
- **MOM**: Method of Moments
- **FEM**: Finite Element Method
3 Modelling of Multilayered IC Packages

Background & Motivation
Packaging

(Def.) Housing and interconnection of ICs to form product

- To take up the slack --- difficulty of Moore's law scaling
- Next-generation packaging --- 3D & more complicated
- Emerging as Limiting Factor for Cost & Performance

Modeling and simulation
Enabler to reduce Cost & achieve Performance

Modeling and simulation techniques/tools for
Next-generation 3D packaging in high demand

[Short-term] To develop fast and accurate modeling techniques
for electrical & electromagnetic analysis of next generation
3D IC packaging and system integration

[Long-term] To explore a multi-physics platform: electrical-optical
-thermal-mechanical modeling

Multi-physics nature
[Mechanical, Thermal, Electrical et. al.]

Multi-scale nature
[nanometer to centimeter & DC to 10s/100s of GHz]

Complexity
[Plenty of vias (intel--40k), signal traces & multiple P/G planes]
3 Modelling of Multilayered IC Packages

Method Overview
Approaches on IC Package Modeling

- Circuit approach
- Field approach
- Coupled circuit-field approach
Wideband Modeling of Complete Signal Paths in the Multi-layered Packages and Board by using the Multilumped Modeling Method

Complete signal path (chip to board)

Reference: I. Ndip, 2005 ECTC
Equivalent Circuit Model of the Complete Signal Path

Complete Signal Paths

Reference: I. Ndip, 2005 ECTC
Model Order Reduction Method/ MacroModel

On-chip Interconnect

Fast 3D Field Solver
  PSTD  FMM

Parameters Extraction
  \{S(s),Y(s) or parasitic parameters\}

Model Order Reduction
  (PRIMA)

Macromodel Synthesis

\[
\frac{d}{dt} x(t) = Ax(t) + Bu(t) \\
y(t) = Cx(t) + Du(t)
\]

Driver/Receiver Circuit Model

EMI Analysis
  (Radiated emission)

Port Waveforms at Interconnect Subnetwork

Signal Integrity Analysis
  by SPICE Simulator

Electrical Performance Analysis for Full Chip

Parallel Computing & Domain Decomposition for IC Package Modeling based on FDTD

Using Parallel FDTD

Iterative Bi-section approach for domain decomposition & Load balancing

Results

Magnetic field distribution at layer FC3

CPU Time spent vs Processors

3 Modelling of Multilayered IC Packages

Recent Development
Semi-analytical Method
New Algorithm Development

Domain-Decomposition Approach

SIP (System in Package) on Silicon Carrier

Different parts are modeled by using different optimized methodologies
Flowchart of Our Algorithm

New Features of the Algorithm Compared to existing techniques

- 2.5 D method to solve 3D problem
- Semi-analytical method – fast but accurate
- Efficiently Modeling large number of vias & Power/ground planes

System-level Electrical modeling of entire package

1. Layout of a Package (Input)
2. Domain Decomposition
  - Inner Domain
    - P/G Planes, Vias, Striplines etc.
  - Top/bottom Domain
    - Ustrip lines, via bends, etc.
3. Parameter Extraction
4. N-Body Scattering Theory (NBST)
5. Network Parameters [Y] or [Z]
6. Equivalent Circuits RLCG
Modeling of Top/Bottom Domain

Integral Equation Method

Equivalent Circuits

[Er-Ping Li, En-Xiao Liu et. al, IEEE EMC Symposium 2007]
N-Body Scattering Theory (NBST) for analyzing coupling among multiple vias in the presence of multilayered P/G planes.

**Superposition:**

\[ E_{\text{total}} = E_{\text{inc}} + E_{\text{scat(multiple)}} \]

Schematic cross sectional view of wave interactions among many cylinders inside an IC package; The total electromagnetic wave is a superposition of the incident and scattered waves.
Inner Domain Modeling

The governing Maxwell’s equations have two independent solutions: the TE (transverse electric) & TM (transverse magnetic) modes. Each of the two modes can be further decomposed into a parallel plate radial waveguide mode and a cylindrical mode.

Modal Expansion

TE & TM Modes

Parallel Plate Radial Waveguide Mode (PPWG)
-- Adjacent P/G Planes

Cylindrical Mode (CYM)
-- Vias

\[ E_z = \sum_{m} \sum_{n} a^E_{mn} \cos(k_m z) Z_n(k_\rho \rho)e^{jn\phi} \quad \text{for TM} \]

\[ H_z = \sum_{m} \sum_{n} a^H_{mn} \cos(k_m z) Z_n(k_\rho \rho)e^{jn\phi} \quad \text{for TE} \]

[Z. Z. Oo, En-Xiao LIU et. al, ECTC 2007]
Multiple Coupling among Large Number of Vias

Scattering among N Vias

\[ \Phi(\rho) = \sum_{q=1}^{N_{\text{via}}} \sum_{m=0}^{M_q} \sum_{n=-N_q}^{N_q} f_{qmn} H_n^{(2)}(k_m \rho_q) e^{jn\phi_q} \cos(\beta_m z) \]

- Scattered fields
- Coefficients of the incident wave (excitation)
- Unknown coefficients of the scattered wave
- \( T (\text{transition}) \) Matrix
- \( \alpha \) Matrix

\[ f_q = \bar{T}_q \left( a_q + \sum_{p=1}^{N_{\text{via}}} \bar{\alpha}_{qp} f_p \right) \]
Test board 2:
- two SMA ports (signal vias)
- thickness 1 mm
- via diameter 0.1 mm
- substrate material 4.1; loss tan 0.02
**Validation: L-shaped P/G Plane and Cut-out Structure**

- An irregular-shaped power/ground plane
  - substrate material 2.65; loss tan 0.003
  - two SMA ports at (61,5) and (10,42)
  - cut-out (15x15) in power/ground plane

Unit: mm

Comparison against Ansoft HFSS

- 101 pins (vias) in three power/ground layers

- 101 Pins (PEC vias)
- Three conductor layers (P/G/P) & 0.8-mm total thickness
- 20 x 20 mm dimension
## Comparison against Ansoft HFSS

<table>
<thead>
<tr>
<th>No. of power/ground layers</th>
<th>No. of vias (pins)</th>
<th>Memory</th>
<th>CPU time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>HFSS</td>
<td>Our Approach</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>20 MB</td>
<td>6 MB</td>
</tr>
<tr>
<td></td>
<td>101</td>
<td>138 MB</td>
<td>43MB</td>
</tr>
<tr>
<td>3</td>
<td>101</td>
<td>420 MB</td>
<td>140MB</td>
</tr>
<tr>
<td></td>
<td>221</td>
<td>Out of memory</td>
<td>500MB</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>50 MB</td>
<td>15 MB</td>
</tr>
</tbody>
</table>

**Package Dimensions:**
20 mm by 20 mm

**Computing resource:**
1.3 GHz CPU, 512 MB memory

**Our approach:**
- About 1/3 of HFSS's memory usage
- About 5 to 15 times faster than HFSS
Simulation tools have been greatly improved in the last 10 years, they are much faster and accurate now, it really could help the EMC engineers to solve number of problems, but not 100%.

The present simulation tools can do:

- predict small scale and the regional EMI,
- quickly predict and diagnose the regional EMI problems, i.e. Where is the major source of the radiations,
- optimize the performance for various designs at lower cost compared to experiments,
- Be able quantitative assessments of insight EM performance, for which experiment is unable to do,
- Overall shorten the design cycles.
The present simulation tools can’t

- Still can’t accurately simulate the entire system level EMI, from components, board to system levels,
- Can’t accurately simulate the large and complex EMC problems,
- No proper tools and accurate methods to simulate the electromagnetic susceptibility, which is nowadays critical for EMC design.
• This presentation gave an overview review of three commonly used numerical Methods for EMC;
  – it may help engineers to choose the right method/tool for the right problem;
  – Integral methods vs. differential methods;
  – Surface methods vs. volume methods;
  – Time-domain methods vs. frequency methods.
The future requirements

- Simulation of Signal integrity and power integrity simulation in real-world entire PCB and package system is still challenge
- Mixed thermal and electrical multiphysics simulation with multi-scale natures
- Comprehensive electromagnetic susceptibility simulation is also required
- A virtual EMC-test lab system should be developed to model the entire system level EMC.
The Dream for EMC Modeling

Virtual EMC Lab

- EMC/EMI standards
- EMC modeling techniques
- Validation
- HPCV computer system

Virtual EMC Lab

Conventional EMC testing house
Thank you for your attention!