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.

  ⇨

  - Principle
  - Advantages/disadvantages
  - Typical Applications
  - Simulators
- **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

$$\mathbf{curl}\ \mathbf{H} = \frac{4\pi}{c}\mathbf{j} + \frac{1}{c}\frac{\partial\ \mathbf{D}}{\partial t}$$

$$\mathbf{curl}\ \mathbf{E} = -\frac{1}{c}\frac{\partial \mathbf{B}}{\partial t}$$

$$div\ \mathbf{D} = 4\pi\ \rho$$

$$div\ \mathbf{B} = 0$$

James Clerk Maxwell
(1831-1879)

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

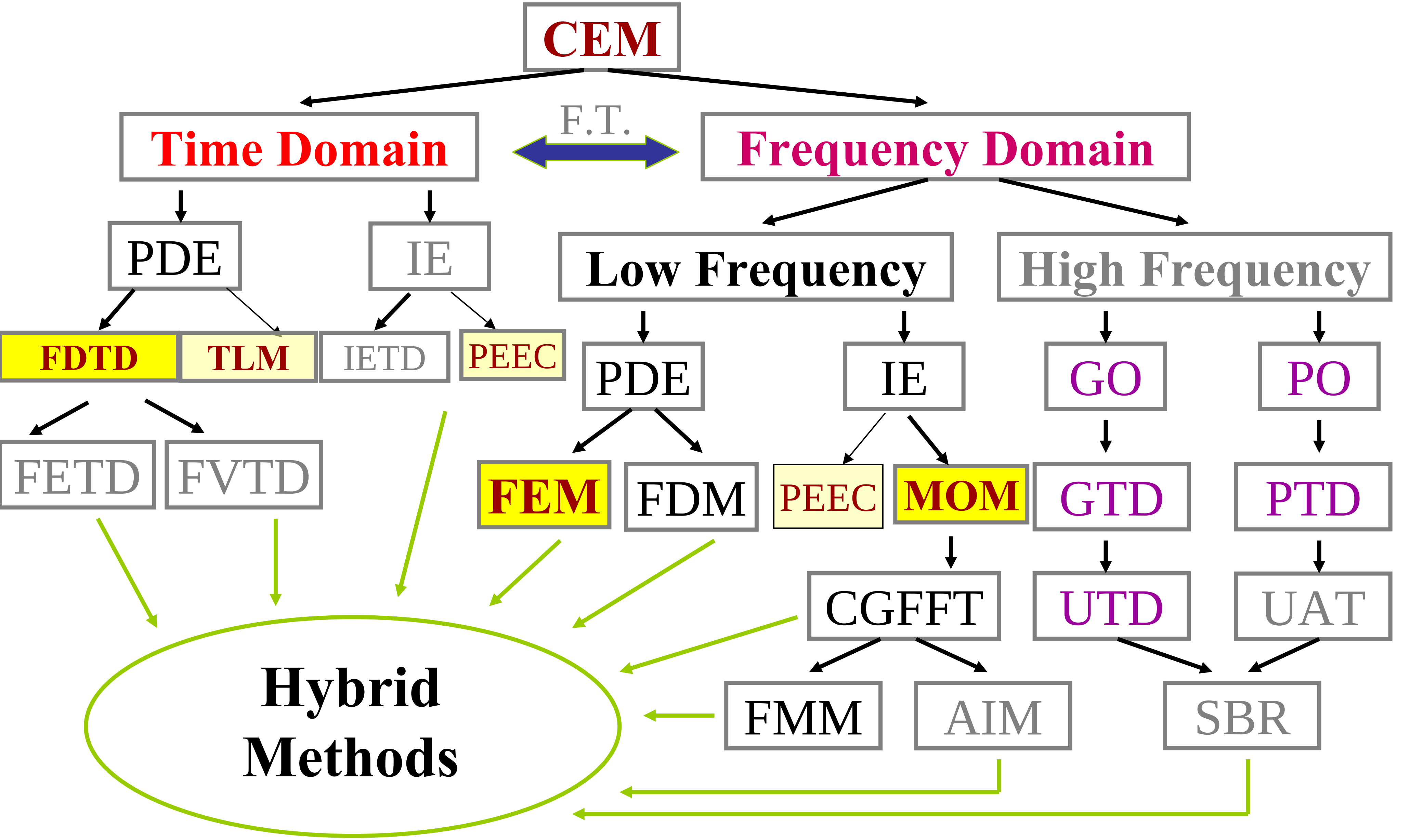
Brief History of Electromagnetic Computation

- 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)
- 1983 P. P. Silvester & R. L. Ferrari, Finite Elements for Electrical Engineers, 1st ed.
- 1985- Extensive developments for EM problems

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



J. M. Jin, FEM, IEEE Press, H.D. Bruns, et al , IEEE Trans on EMC, vol. 49, no. 2, 2007

Computational Electromagnetic for EMC

- **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

H.D. Bruns, et al , IEEE Trans on EMC, vol. 49, no. 2, 2007, C. Paul, Intr of EMC, John Wiley

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)<

$$\mathcal{L}\phi = f$$

Linear Operator (integral)

Unknown function to be determined

known function (excitation)

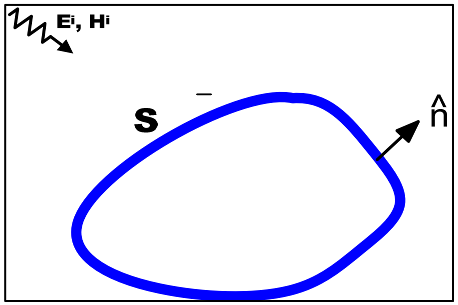
An example of the electric field integral equation (EFIE) for a perfectly conducting (PEC) object illuminated by an incident field

$$\hat{n}\times\mathbf{E}^{i}(r) = \hat{n}\times\int_{S}\left[j\omega\mu\mathbf{J}_{s}G(r,r') + \frac{1}{j\omega\varepsilon}\left(\nabla'_{s}\cdot\mathbf{J}_{s}\right)\nabla' G\right] ds' \qquad r\in S$$

Known (Incident field)

Green's function

Unknown (surface current)



Method of Moments (MoM)

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

$$\mathcal{L}\phi = f$$

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

$$\phi = \sum_{n=1}^{N} \alpha_n v_n$$

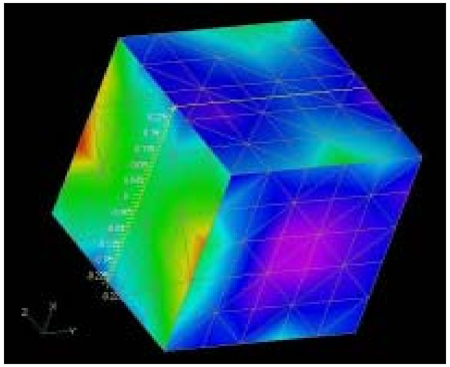
The original integral equation becomes:

$$\sum_{n=1}^{N} \alpha_n \mathcal{L} v_n = f$$

- **Testing (conversion)**

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

$$\sum_{n=1}^{N} \alpha_n < w_n, \mathcal{L} v_n > = < w_n, f > \quad \Longrightarrow \quad [Z]\{\alpha\} = \{b\}$$



- **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 inhomegeneity of an object by equivalent volume electric and magnetic currents that radiate in background medium.**
  - **Suitable for penetrable (inhomogeneous) media**

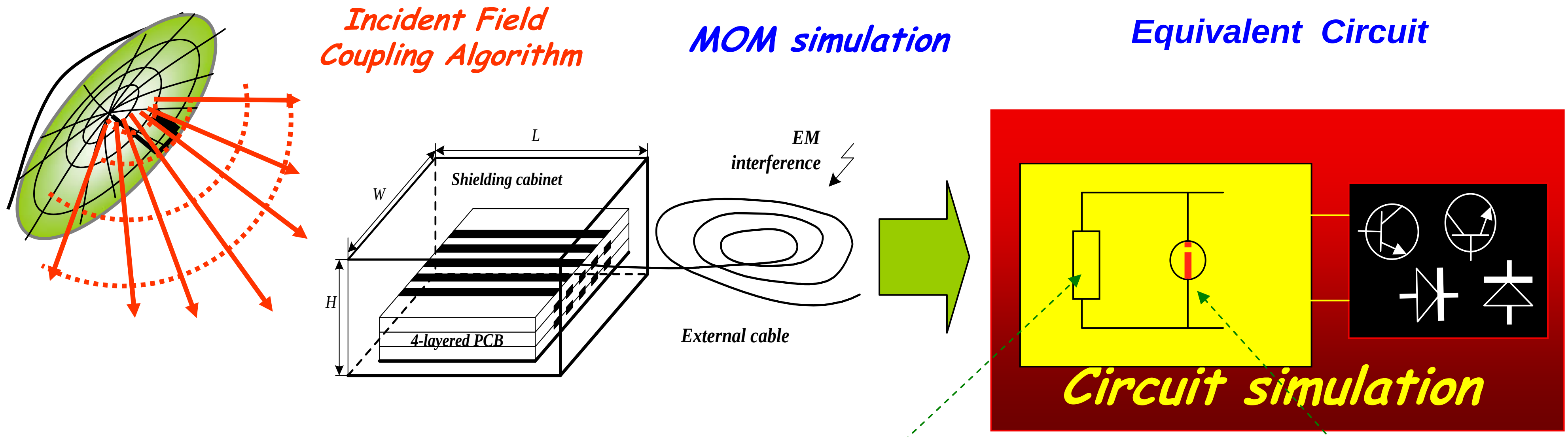
Basis functions

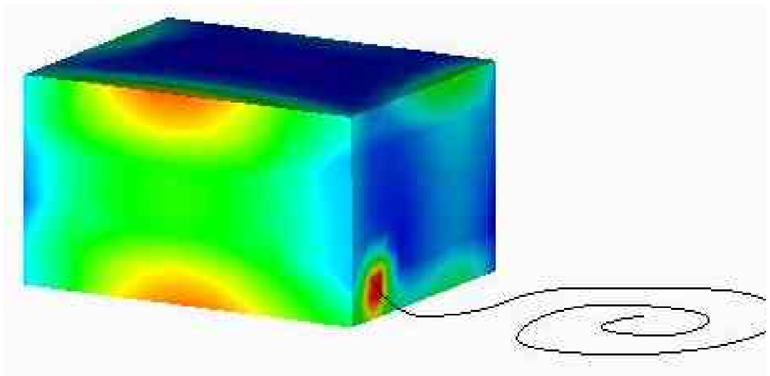
- Entire-domain basis function (regular domain)
- Sub-domain basis function (complicated and arbitrary domain)

  Examples ---

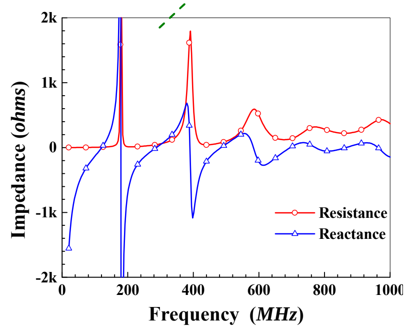
  Pulse, roof-top, triangular, hexahedron and tetrahedron)

MOM for Simulation of EM Susceptibility

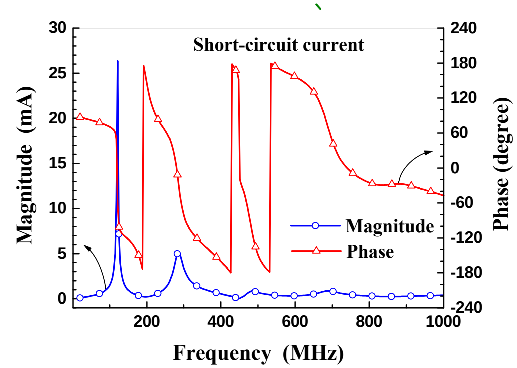




Surface current



Equ Impedance

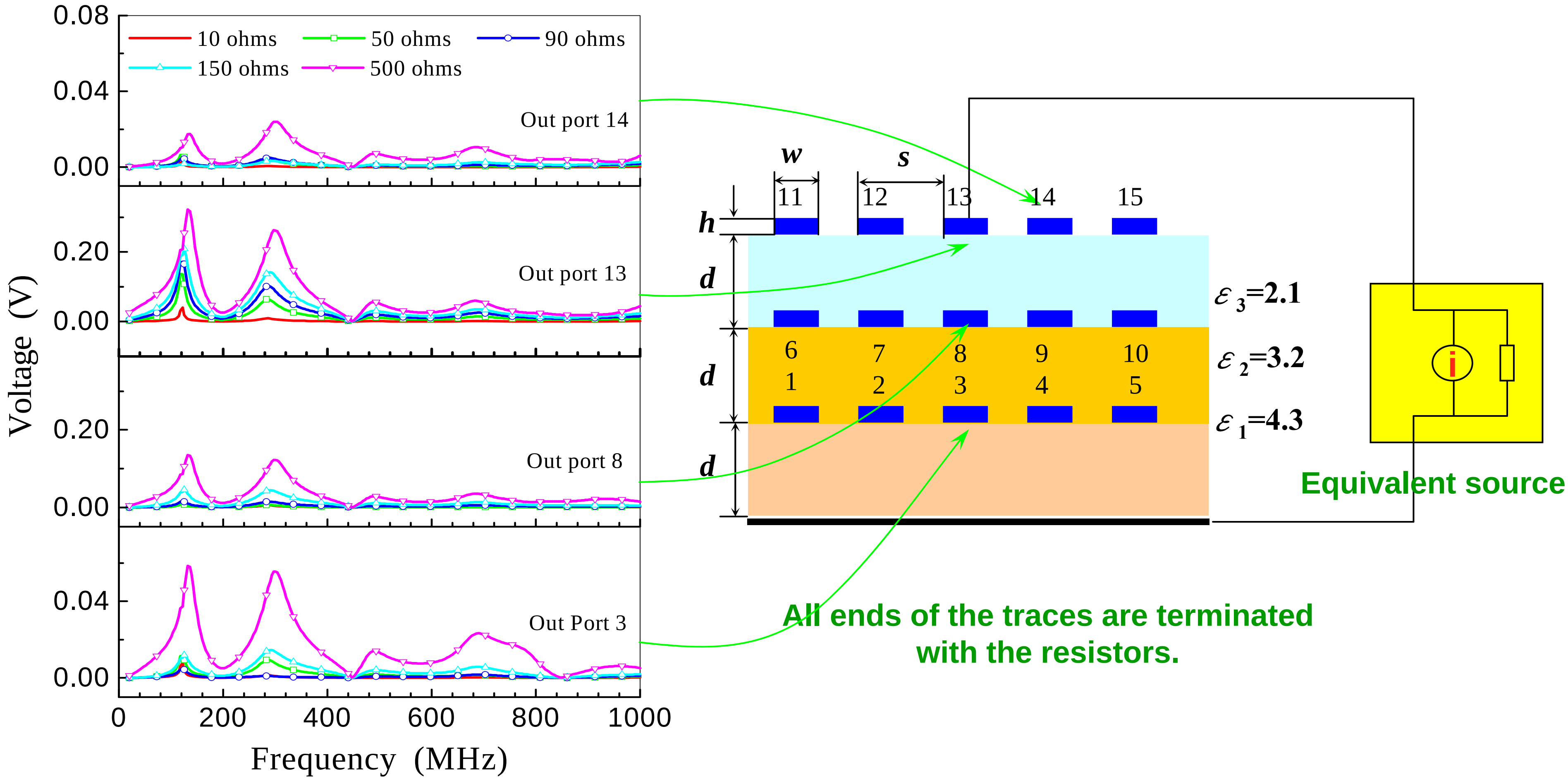


Equ Current

Y W Liang and E P Li,A systematic coupled approach for EM susceptibility analysis of a shielded device with multilayer circuits, IEEE Trans. On EMC, vol.47, no.4, 2005

MOM for Simulation of EM Susceptibility

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



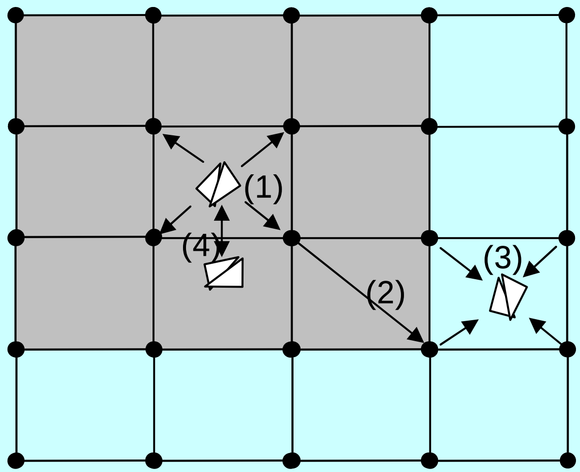
Y W Liang and E P Li,A systematic coupled approach for EM susceptibility analysis of a shielded device with multilayer circuits, IEEE Trans. On EMC, vol.47, no.4, 2005

Method of Moments: Fast Algorithm

Fast Algorithm

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

AIM
(adaptive integral method)

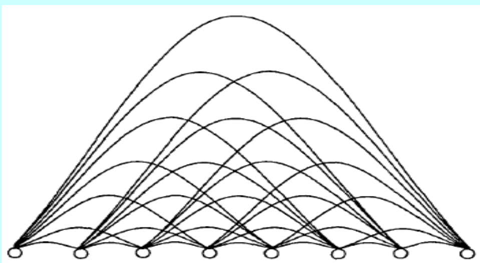


2-D representation of the procedures of the AIM algorithm

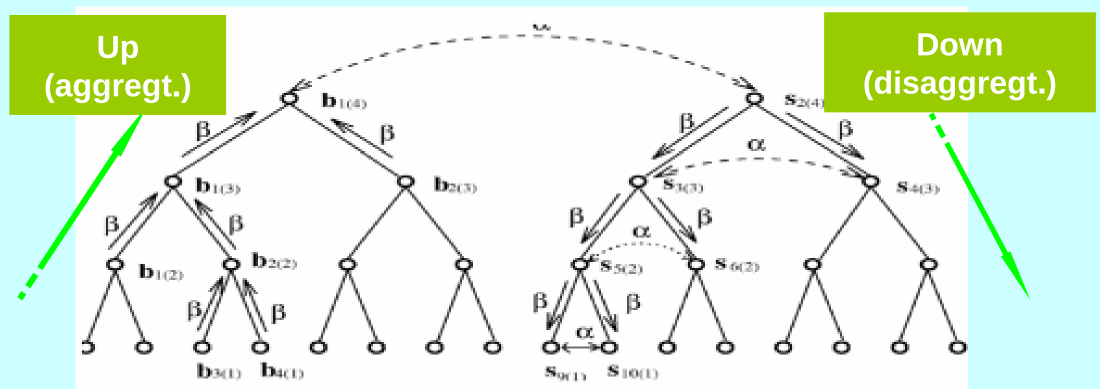
(1) Project panel current density onto grid
(2) Compute potentials using FFT
(3) Interpolate grid potentials onto panels
(4) Compute near zone interactions directly

Method of Moments: Fast Algorithm

FMM & MLFMM (fast multipole)



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



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

$$\mathbf{MoM:}\quad \mathbf{Z}\cdot\boldsymbol{\alpha}=\mathbf{b}\qquad \sim O(N^2)$$

Connection between 'hubs'

Interaction from low-level to upper level 'hub'

$$\mathbf{FMM:}\quad \left(\mathbf{Z}_{NN}+\mathbf{V}^{+}\,\mathbf{T}\,\mathbf{V}\right)\boldsymbol{\alpha}=\mathbf{b}\qquad \sim O(N\log N)$$

Near-interaction

Interaction from upper-level 'hub' to low-level (elements)

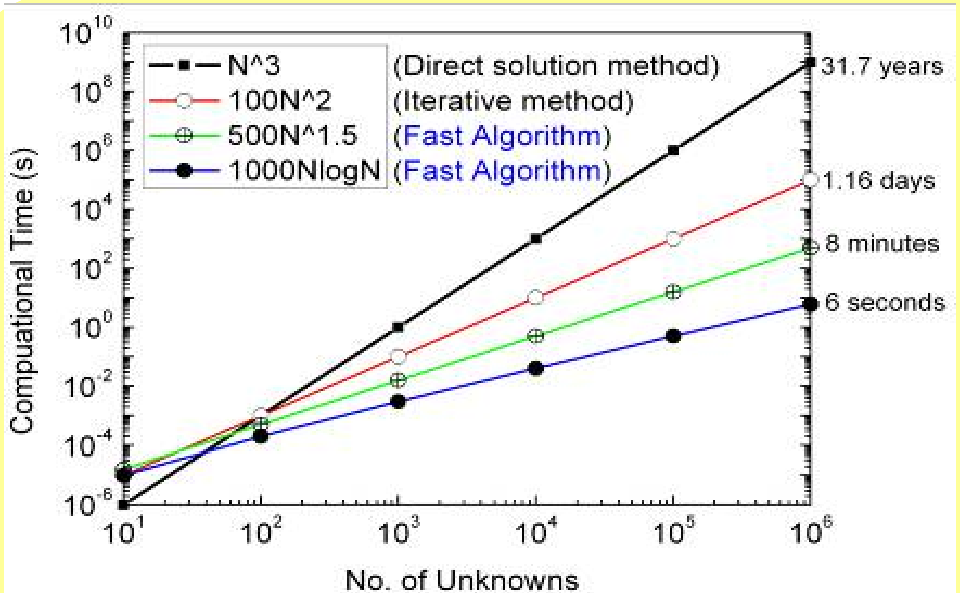
[Ref.] W. C. Chow, http://www.ccem.uiuc.edu/chew/aces2000_files/frame.htm

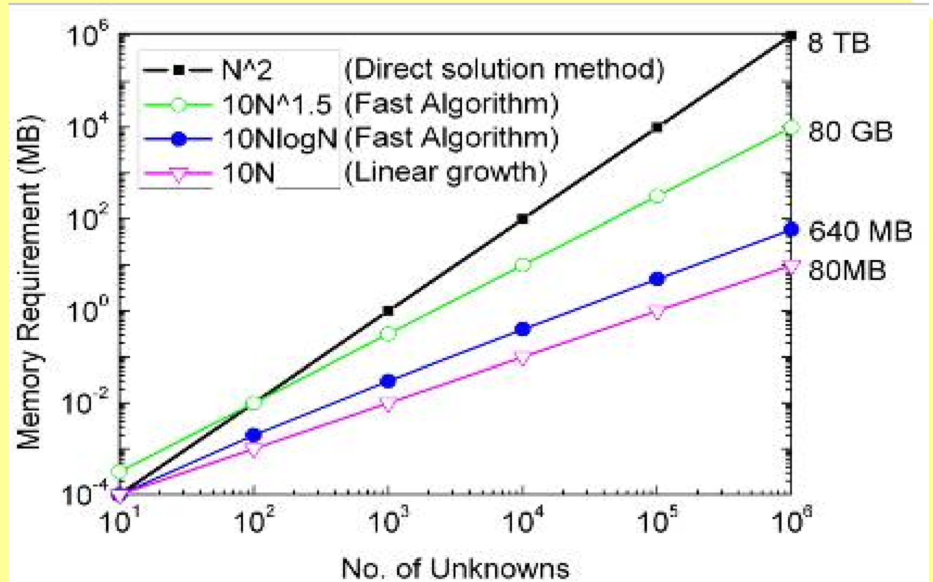
Method of Moments: Fast Algorithm

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 algrorithm

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 Iterscience

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.**

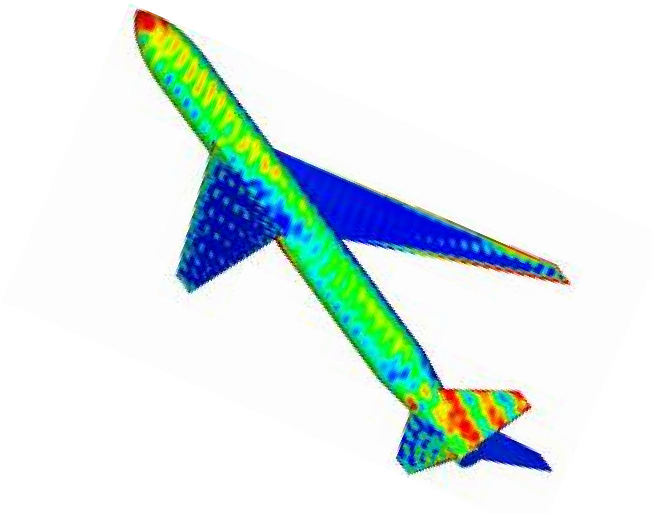
- IE3D
  - **MMICs, RFICs, LTCC circuits, microwave/millimeter-wave circuits, IC interconnects and packages, patch/wire antennas, and other RF/wireless antennas**
- … …

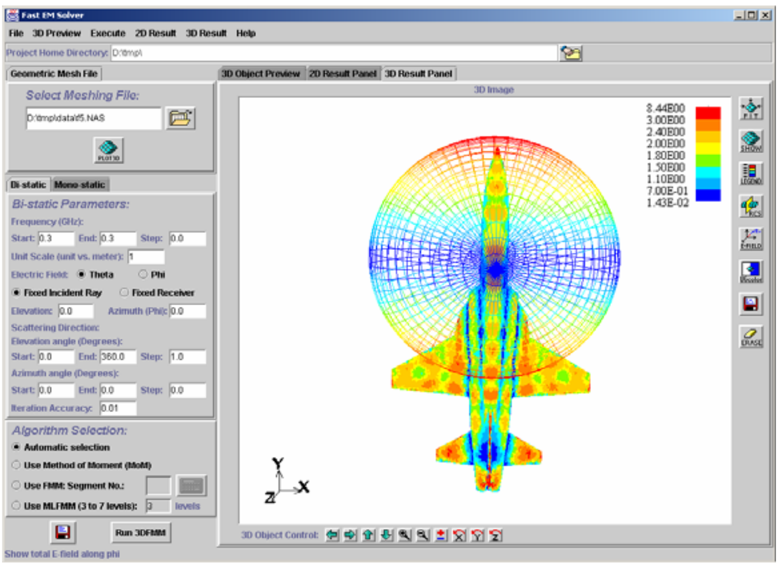
Examples

Applications: Aviation industry

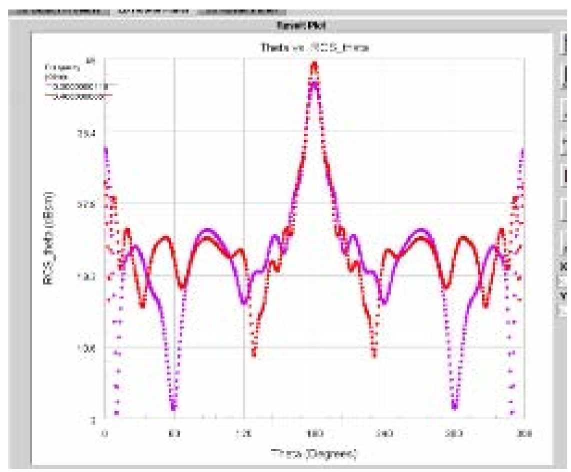
Method: MoM with FMM

Solver developed at IHPC, Singapore

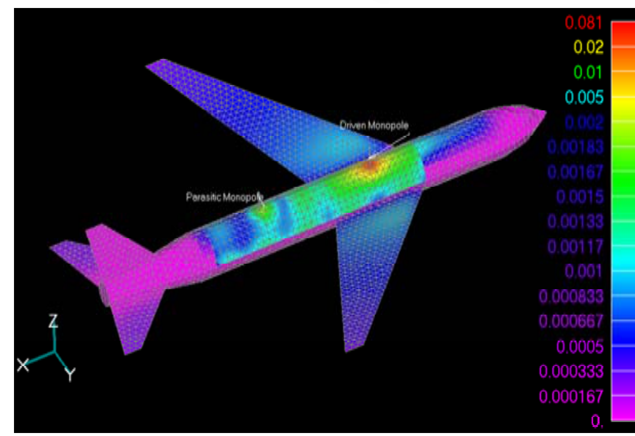




GUI



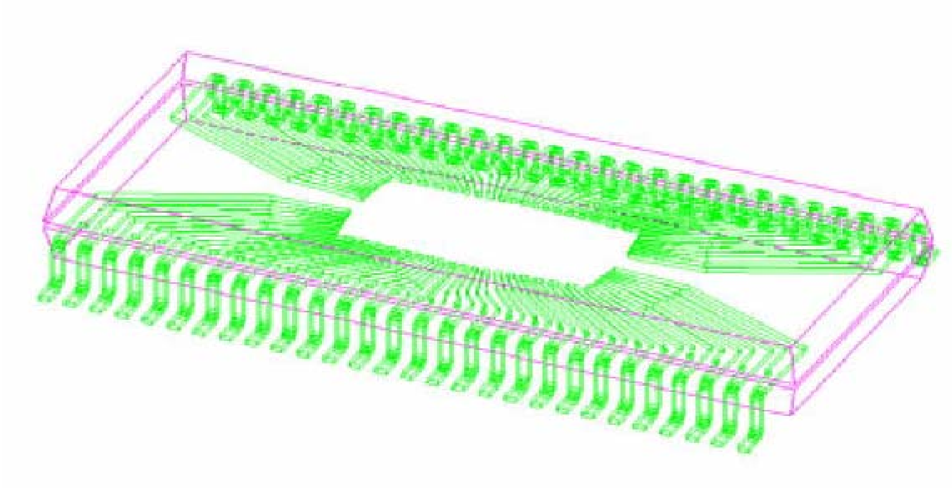
RCS results



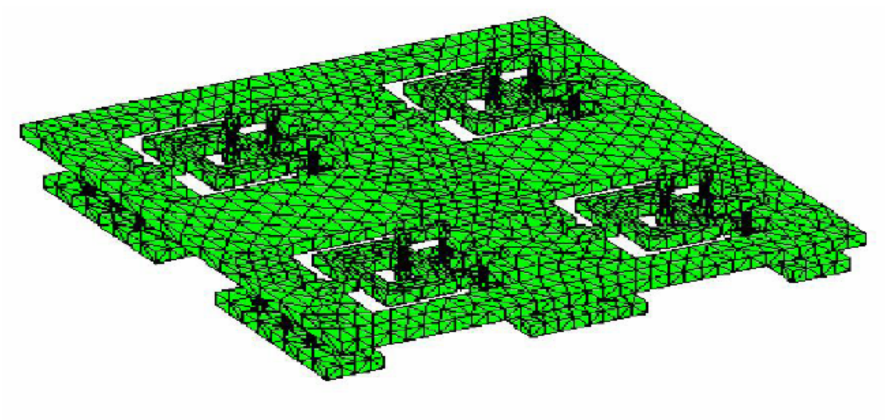
Current distribution

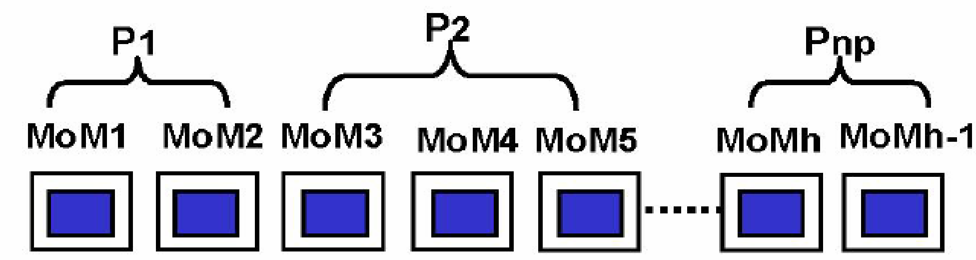
[Ref.] E. P. LI , et. al., IHPC Fast Algorithm Development -- Research Report, 2005.

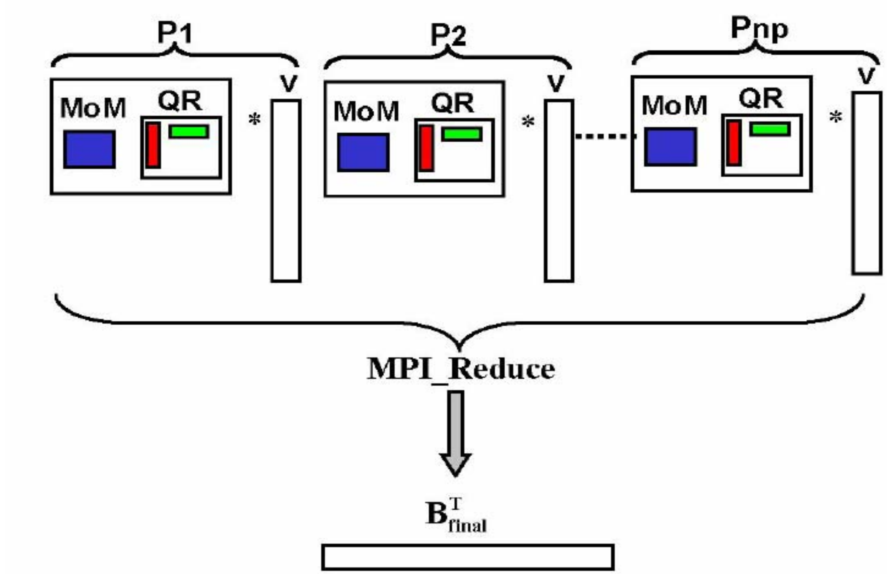
Parallel Fast Integral Equation Simulation Method



Packaging Structure

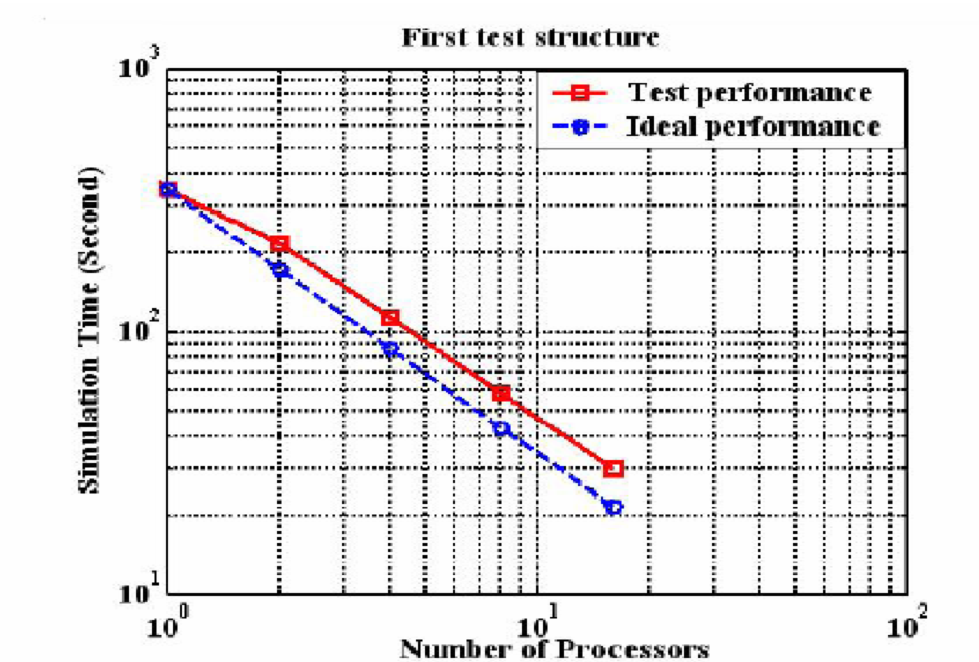


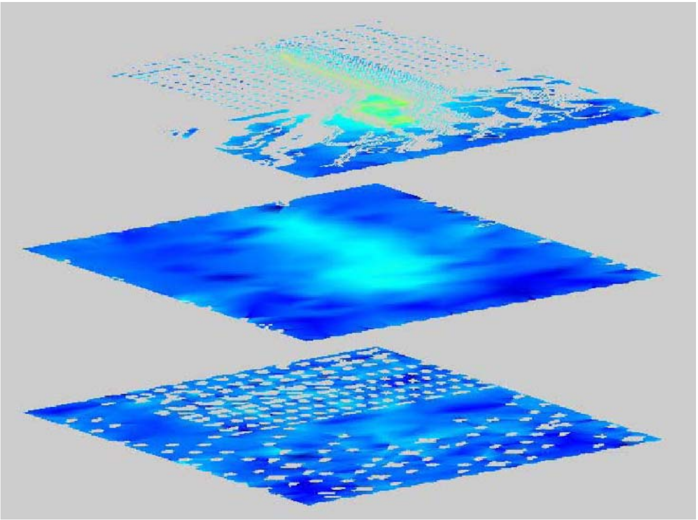


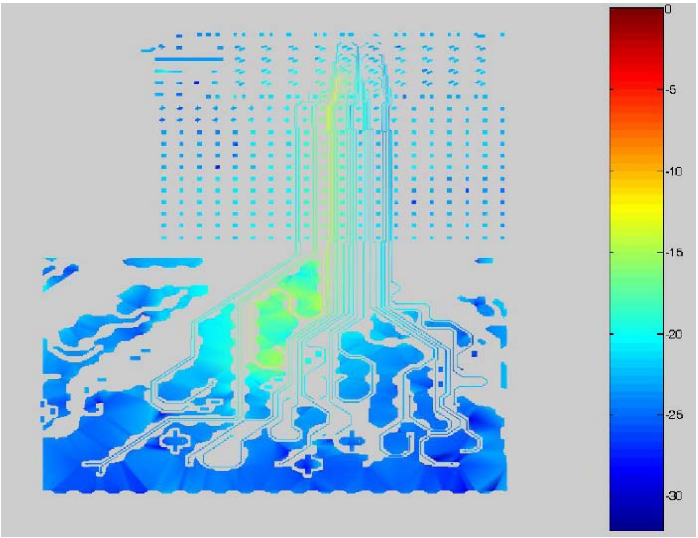


V. Jandhyala,et al, IEEE EPEP, pp287-290, 2006

Simulation Time vs Number of Processors





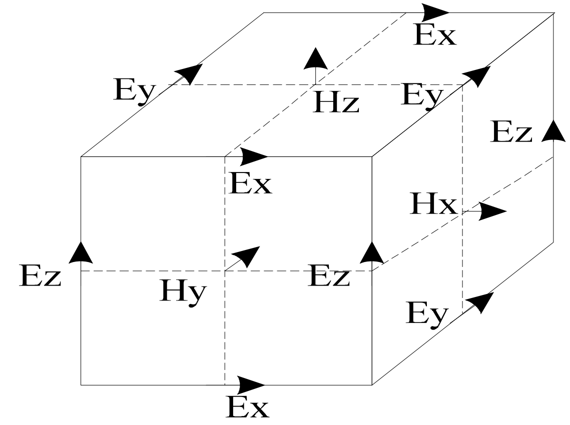


2 Review of Numerical Methods

Finite-Difference Time-Domain Method (FDTD)

Finite-Difference Time-Domain Method (FDTD)

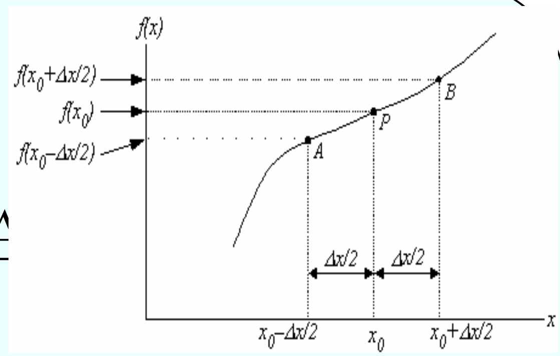
- Finite Difference Time-Domain (FDTD) method, first introduced y K.S. Yee in 1966, and later developed by Taflove and others, is a direct solution of Maxwell's Time-dependent curl equations.
- It is a robust, easy-to-understand , easy-to-implement techniques. It is one of the most popular time-domain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



$$\begin{cases} \nabla \times E = -\mu \dfrac{\partial H}{\partial t} \\ \nabla \times H = \sigma E + \varepsilon \dfrac{\partial E}{\partial t} \end{cases}$$

$$\frac{df(x_0)}{dx} = f'(x_0)$$

$$\cong \frac{f(x_0 + \Delta x/2) - f(x_0 - \Delta}{\Delta x}$$

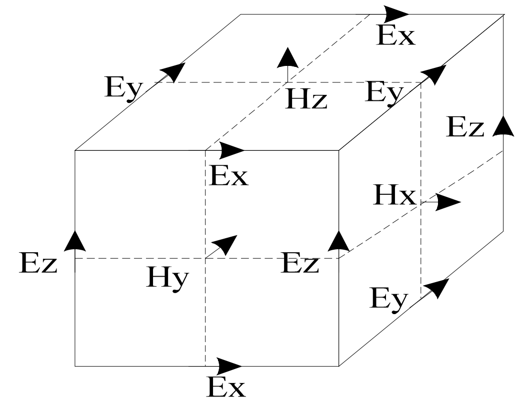


$$H_x\Big|_{(i,j,k)}^{n+\frac{1}{2}} = H_x\Big|_{(i,j,k)}^{n-\frac{1}{2}} - \frac{\Delta t}{\mu}\left(\frac{E_z\big|_{(i,j+1/2,k)}^{n} - E_z\big|_{(i,j-1/2,k)}^{n}}{\Delta y} - \frac{E_y\big|_{(i,j,k+1/2)}^{n} - E_y\big|_{(i,j,k-1/2)}^{n}}{\Delta z} \right)$$

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

$$\Delta t \le \frac{1}{\sqrt{1/\Delta x^2 + 1/\Delta y^2 + 1/\Delta z^2}}$$



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

K S Yee, IEEE Trans A&P, vol.14 1966

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

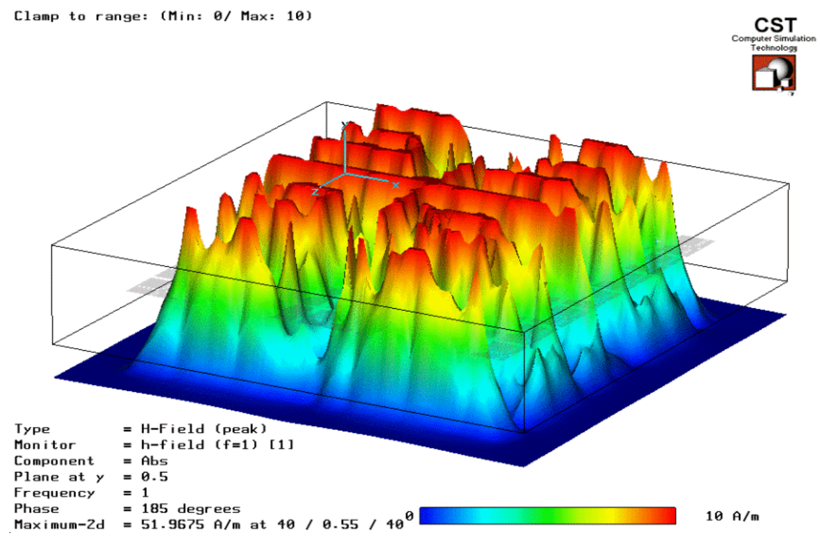
Commercial simulators

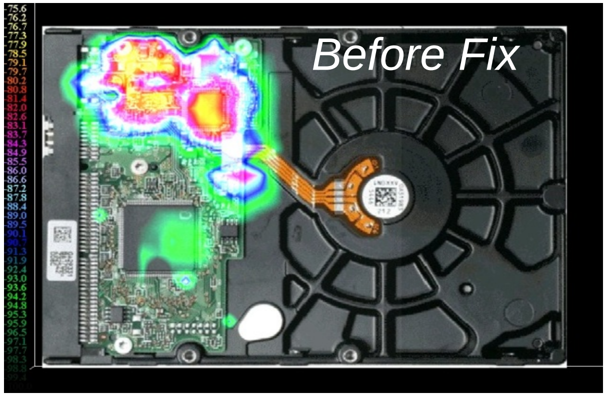
- CST MicroWave STUDIO®
  - **Based on the Finite Integration Technique (FIT)**
  - **Full-wave electromagnetic field simulation software**

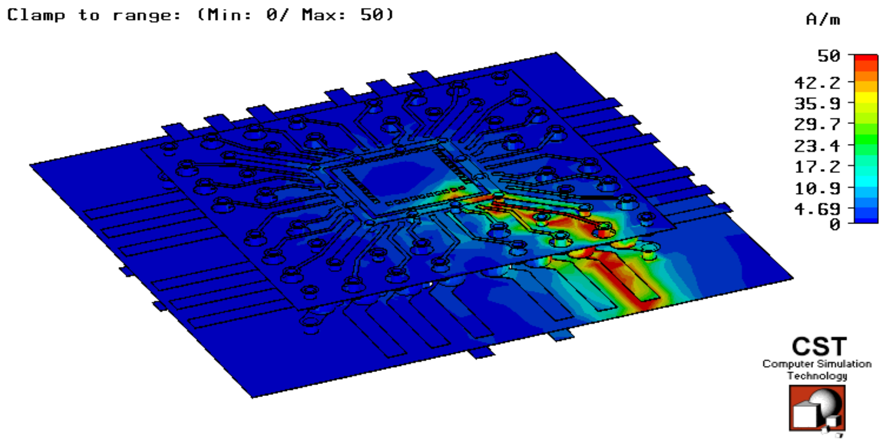
- Remcom XFDTD
  - **Applications including microwave circuits, antennas, EMC, Scattering, Photonics, Bio-EM, etc.**

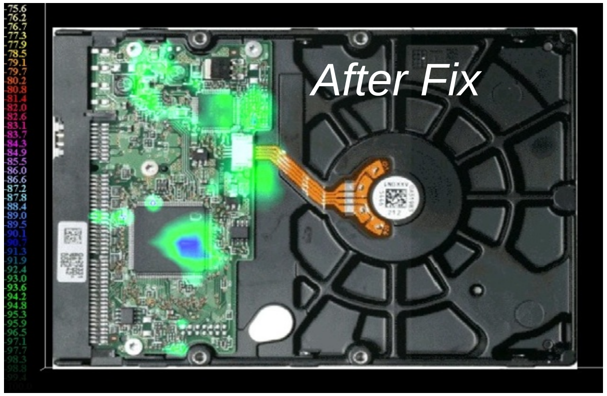
- …

Examples for SI, EMI







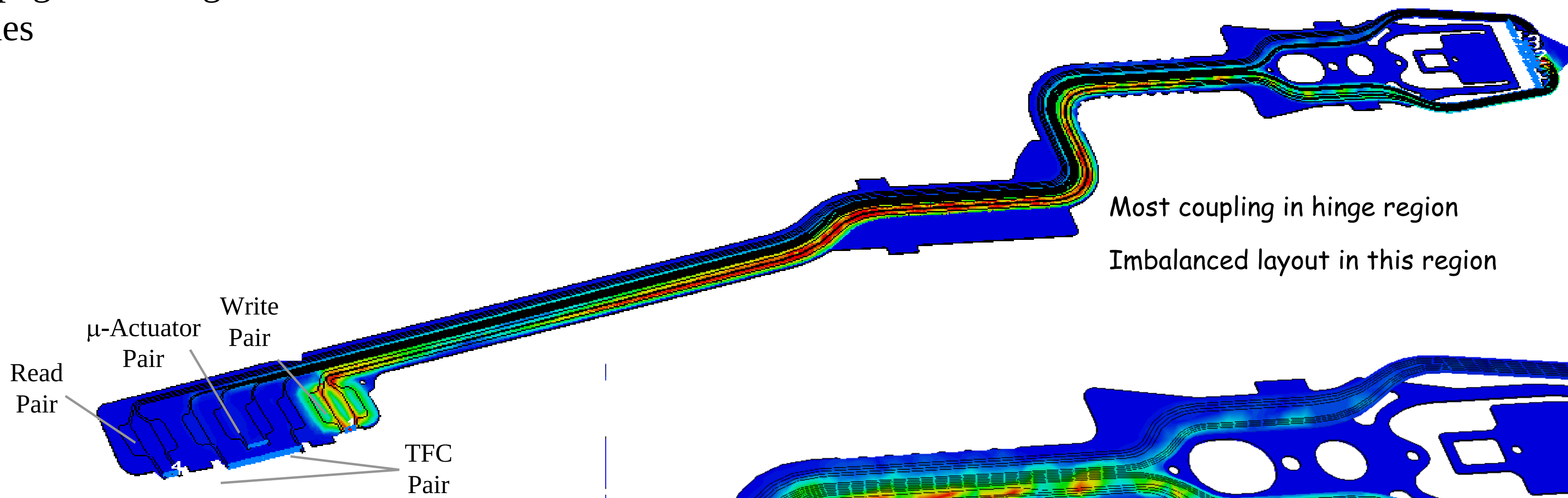


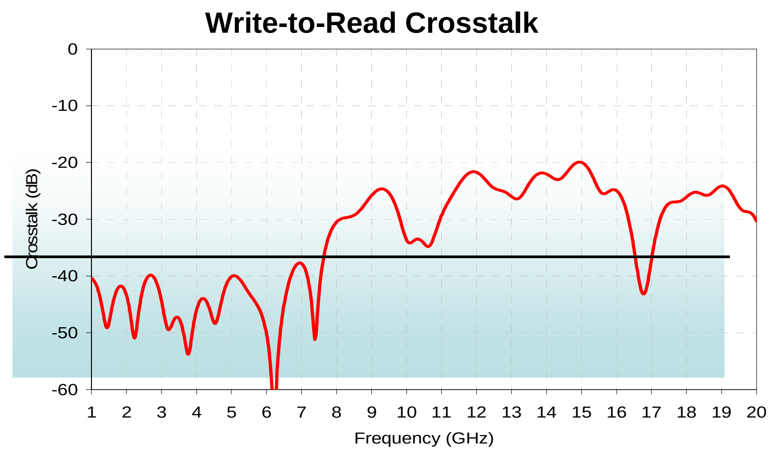
Courteous of CST, Hitachi Data storage

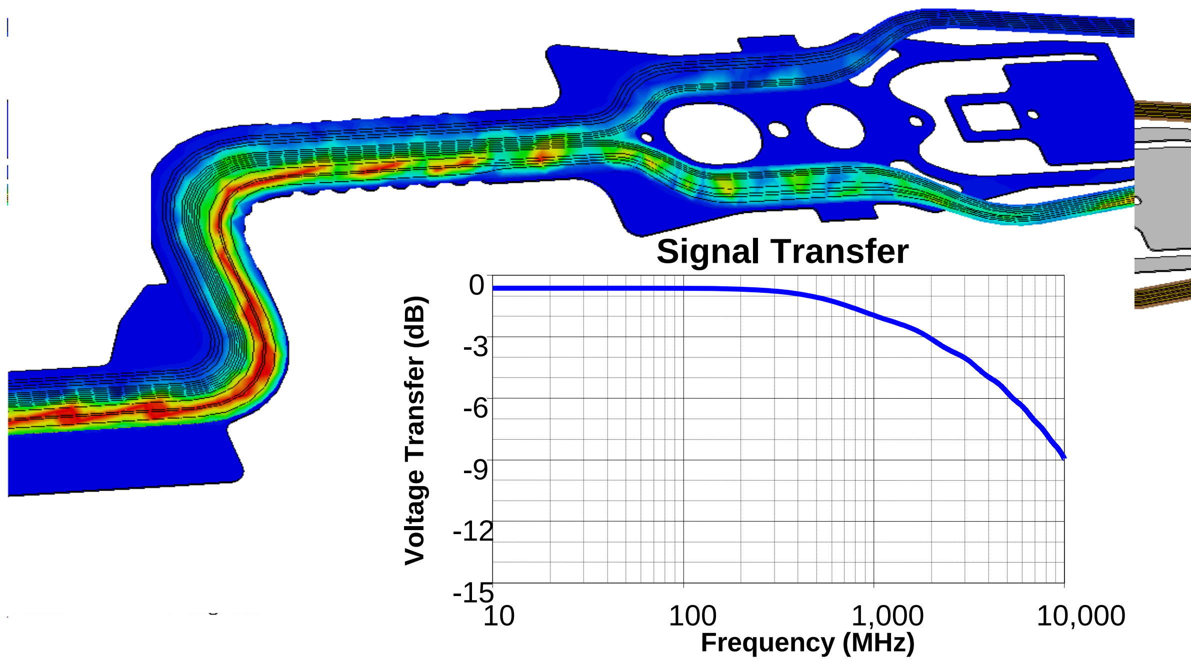
Examples

•Crosstalk is concerned at dense path

•Signal propagation along the lines and interference the adjacent lines







Courteous of CST, Hitachi Data storage

2 Review of Numerical Methods

<u>Finite Element Method (FEM)</u>

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]

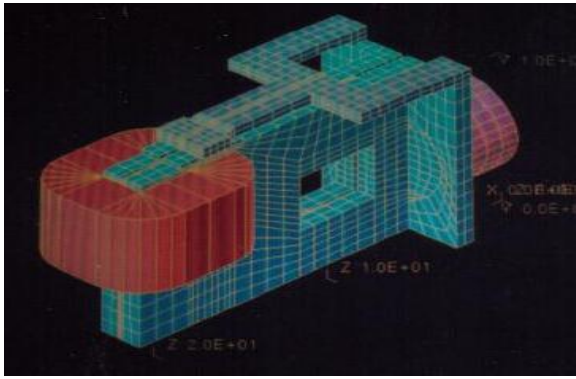
  - Variational method: Minimizing an energy functional

3D time harmonic EM problem→

$$F = \int_V \left\{ \frac{\mu |H|^2}{2} + \frac{\varepsilon |E|^2}{2} - \frac{J \cdot E}{2j\omega} \right\} dV$$

energy stored in magnetic & electric fields

energy dissipated/supplied by conduction currents



Procedures of FEM Analysis:

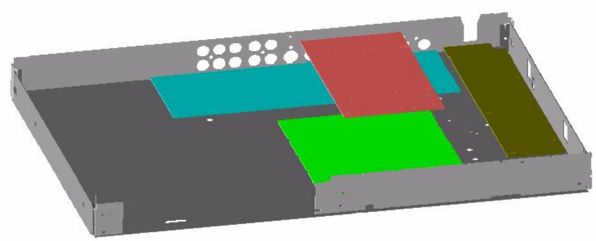
- Discretizing solution regions into finite number of *subregions* or *elements*
- Deriving governing equations (elemental equation) for a typical element
- Assembling of all elements in the solution region to form matrix equation
- Solving the system of equations obtained.

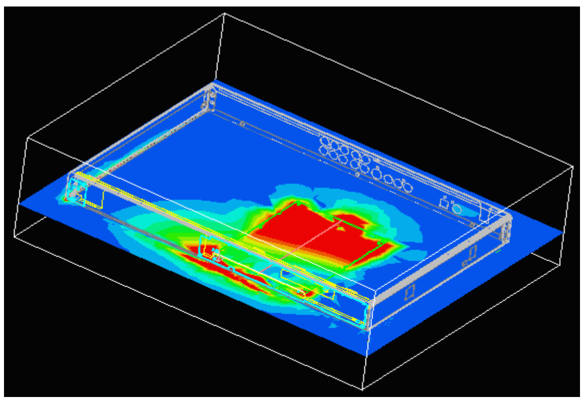
Finite Element Method (FEM)

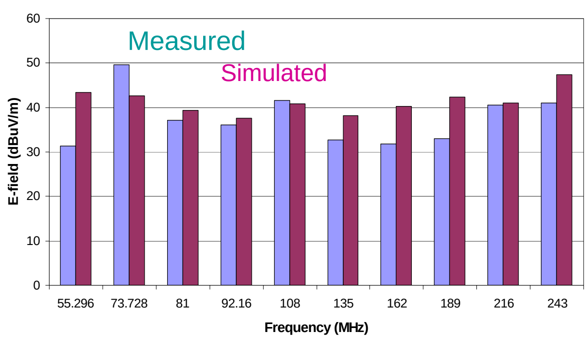
- **Features:**
  - Remarkable advantage of FEM is the flexibility in terms of modeling any complicated geometries, distribution of media.
  - Good handling of inhomogeneous medium (Each element can have different material property)
  - Sparse matrix equation (each element only interacts with elements 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:**

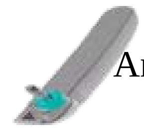
  High-order ABC, domain decomposition, high-order elements
- **Commercial Software**
  - Ansoft HFSS
  - … …

EMI Simulation Examples

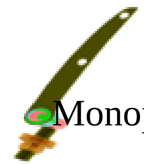




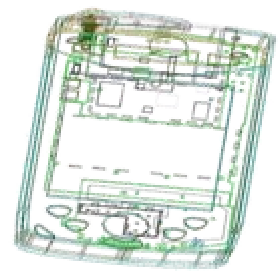




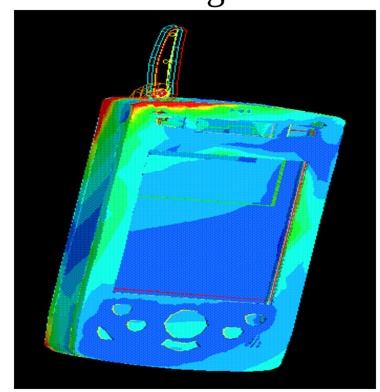
Antenna with Mould Bushing



Monopole Model



Wire-frame Model of PDA



E-field on Casing

2 Review of Numerical Methods

Comparison of Three CEM Methods

Comparison of Three CEM Methods

Methods→	FDTD	MOM	FEM
Principle	Direct solution of Maxwell's equations	Need Frequency-dependent Green's function	Variational principle (minimizing energy functional)
Equation	Differential equation	Integral equation	Differential equation
Transient or steady state	Time-domain method; Obtain responses over a broad band frequencies by Fourier transform	Frequency domain method -- response at one frequency for one solution of the matrix equation	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

[Ref.] M. Sadiku and A. F. Peterson, IEEE Proc. 1990 Southeastcon, pp.42-47

Comparison of Three CEM Methods

Methods→	FDTD	MOM	FEM
Geometry materials	Inhomogeneity easy Arbitrary shape – staircase error	Inhomogeneity difficult	Nonlinearity, ihhomogeneity easy
Meshing	Entire domain discretized	Normally only surfaces discretized	Entire domain discretized
Matrix equation	No matrix equation	Dense matrix	Sparse matrix
Boundary treatment	Open boundary difficult Absorbing boundary needed	Open boundary easy	Open boundary difficult Absorbing boundary needed
Suitable problems	Most developed time domain method; applicable to a variety of electromagnetic problems	More efficient to deal with open domain problems involving impenetrable (PEC) or homogeneous objects	More efficient for closed region problems involving complex geometries & inhomogeneous media objects;

3 Modelling of Multilayered IC Packages

Background & Motivation

Packaging

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

Background

- ❖ 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

Motivation

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

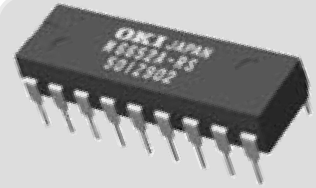
Objectives

[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

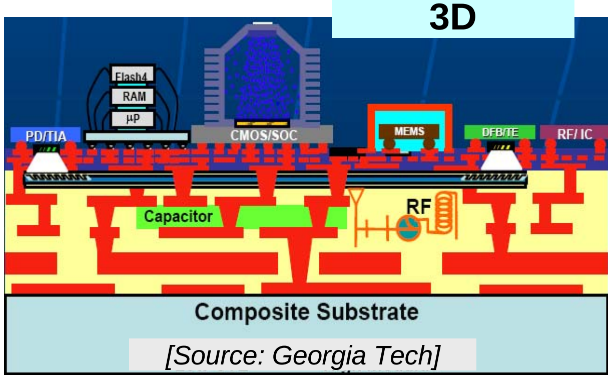
Challenges

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]

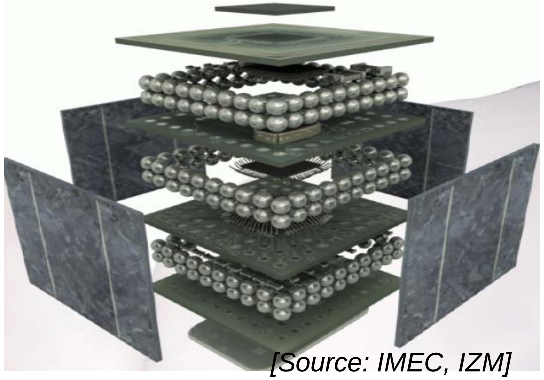


- Present -
2D

- Future -
3D



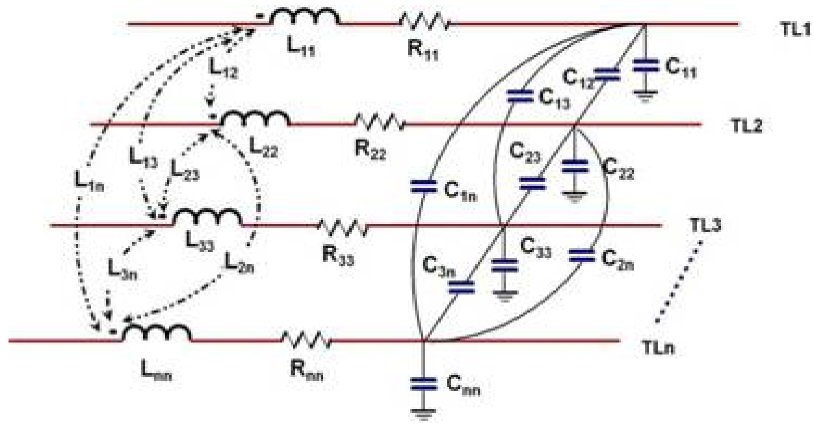
[Source: Georgia Tech]


[Source: IMEC, IZM]

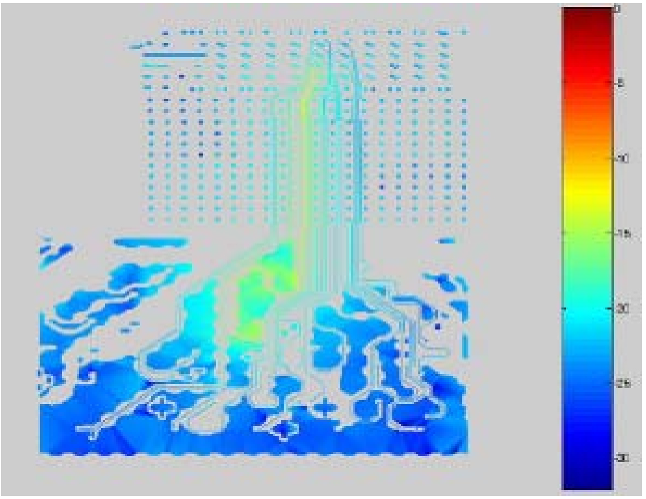
3 Modelling of Multilayered IC Packages

Method Overview

Approaches on IC Package Modeling

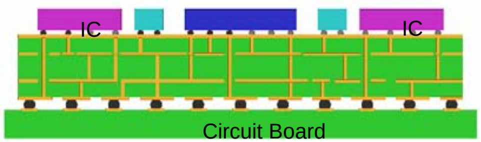


- ❑ Circuit approach
- ❑ Field approach
- ❑ Coupled circuit-field approach



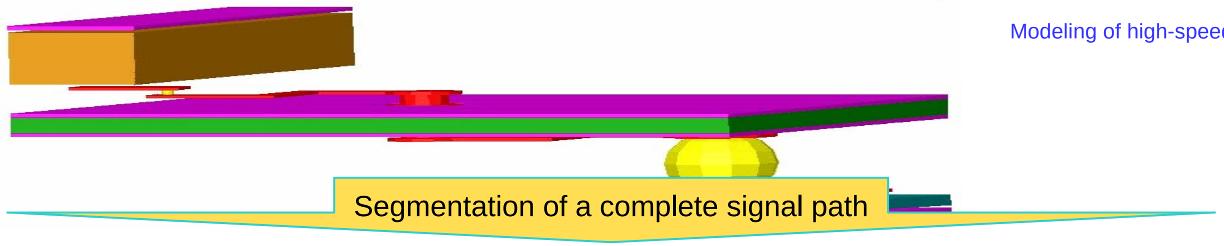
Wideband Modeling of Complete Signal Paths

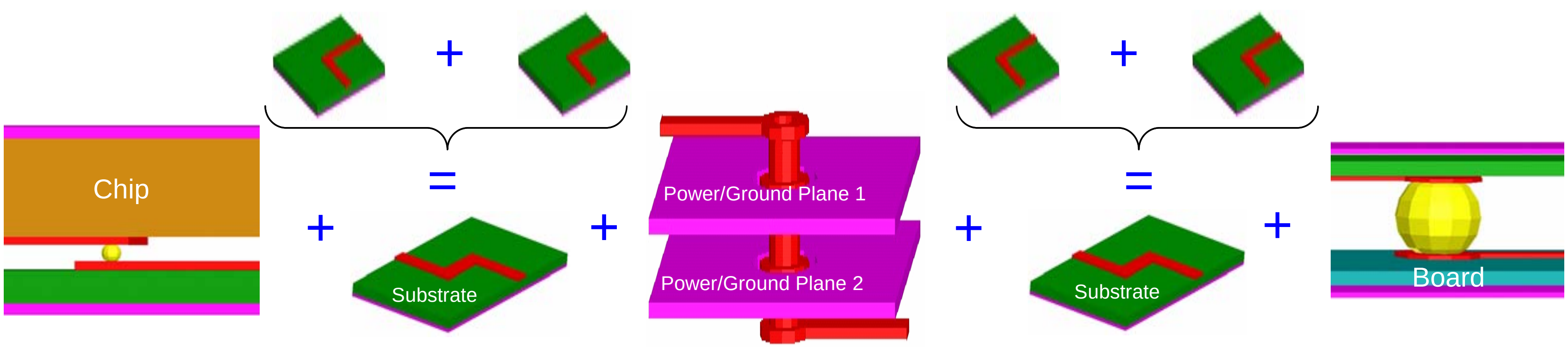
in the Multi-layered Packages and Board by using the Multilumped Modeling Method



Modeling of high-speed system in package integration

Complete signal path (chip to board)

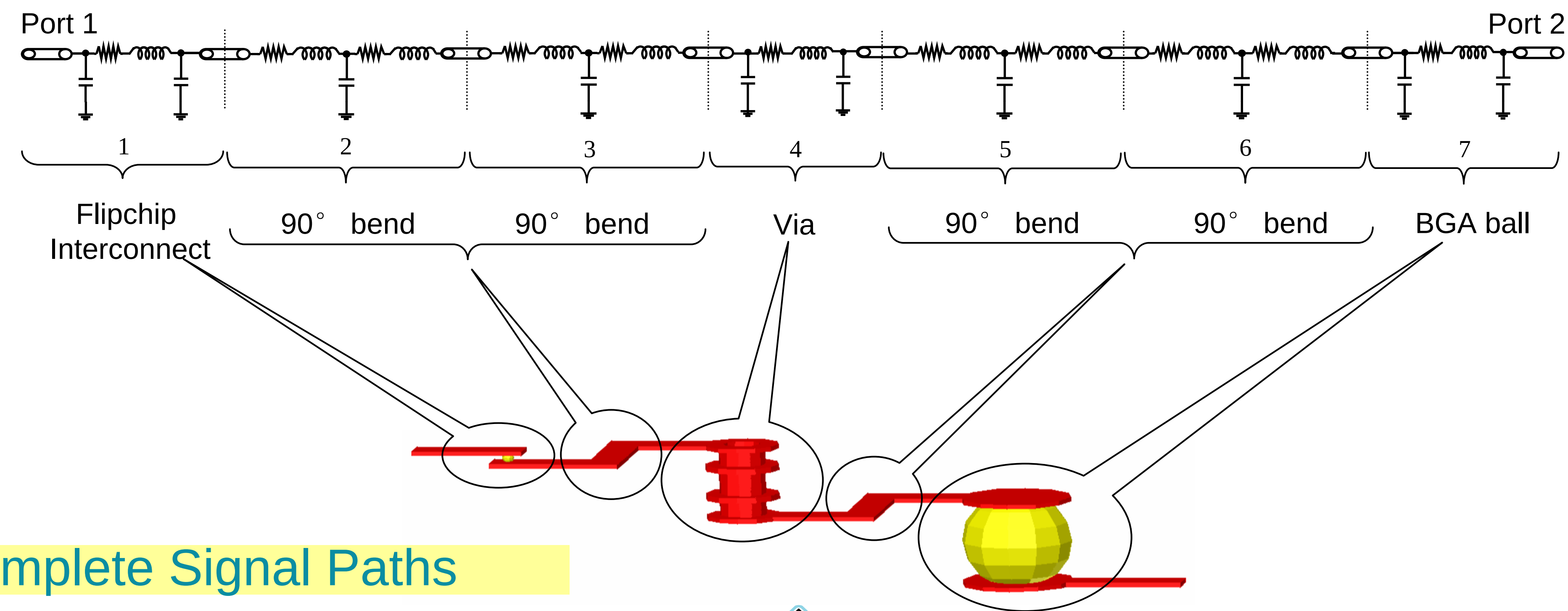




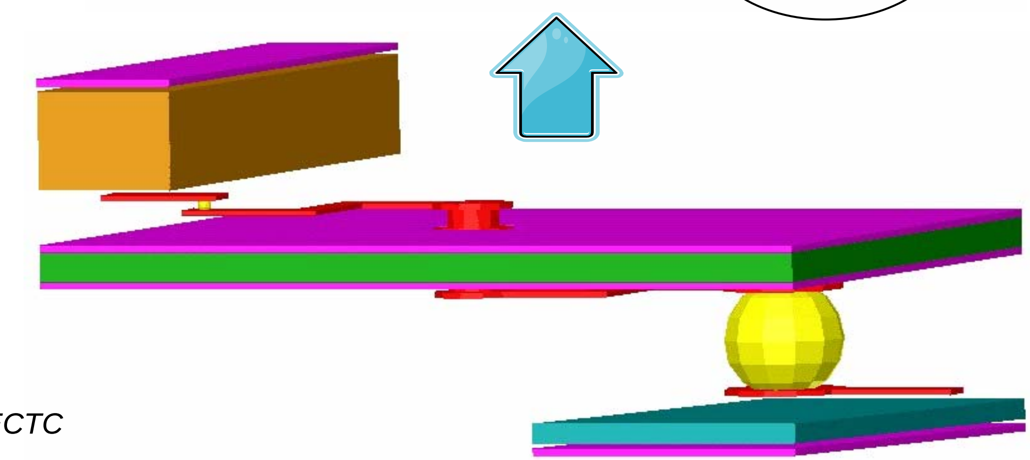
Flip chip interconnect + µstrip package trace with two 90° bends + Through-hole via (µstrip to µstrip transition) For illustrative reasons, dielectric layers above plane 1, between both planes and beneath plane 2, are removed + µstrip package trace with two 90° bends + BGA ball

Reference: I. Ndip, 2005 ECTC

Equivalent Circuit Model of the Complete Signal Path



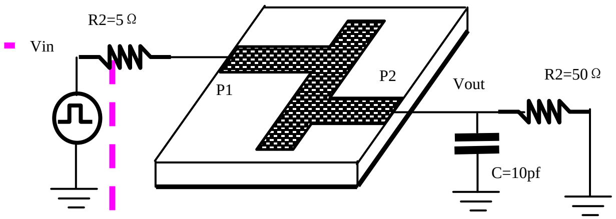
Complete Signal Paths



Reference: I. Ndip, 2005 ECTC

Model Order Reduction Method/ MacroModel

On-chip Interconnect



Fast 3D Field Solver

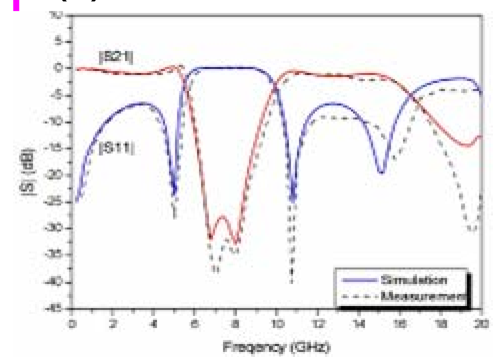
PSTD	**FMM**

(2)

(2)

EMI Analysis (Radiated emission)

(2)



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

Port Waveforms at Interconnect Subnetwork

(2)

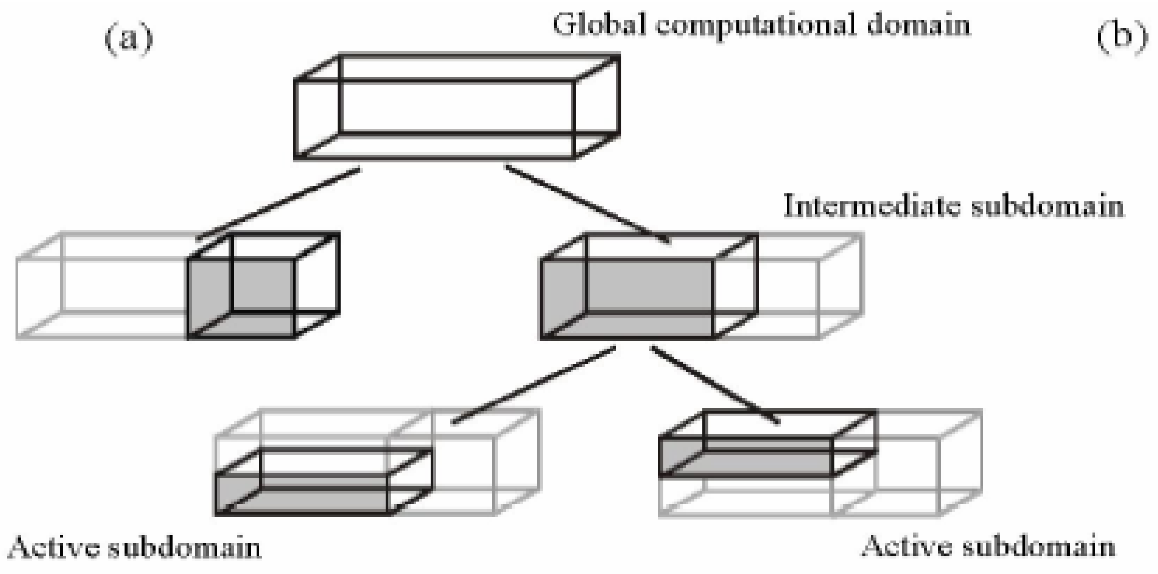
Signal Integrity Analysis by SPICE Simulator

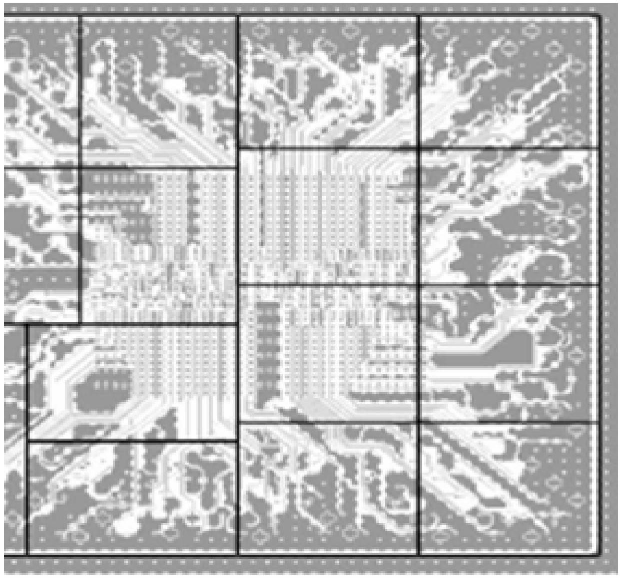
Electrical Performance Analysis for Full Chip

E P Li, E X Liu, L W Li, IEEE Trav Adv. Packg. Vol 27, 2004

Field Model-Full Wave Model

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



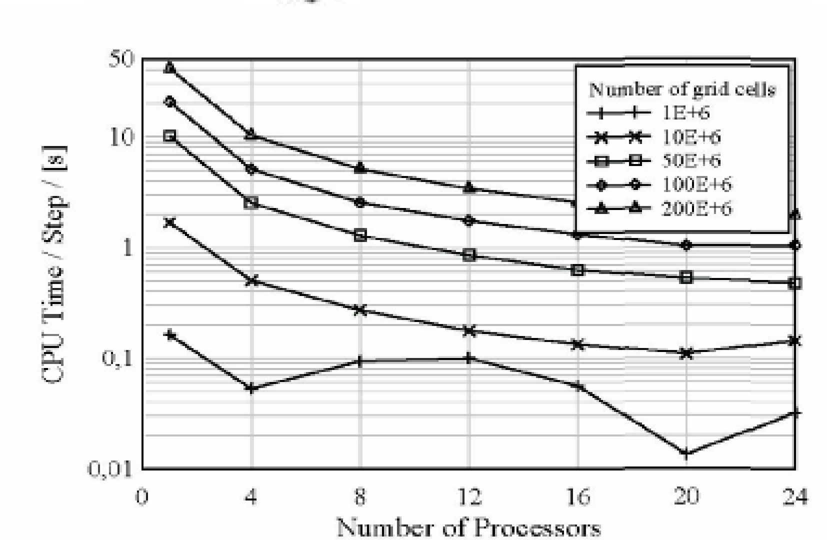


Using Parallel FDTD

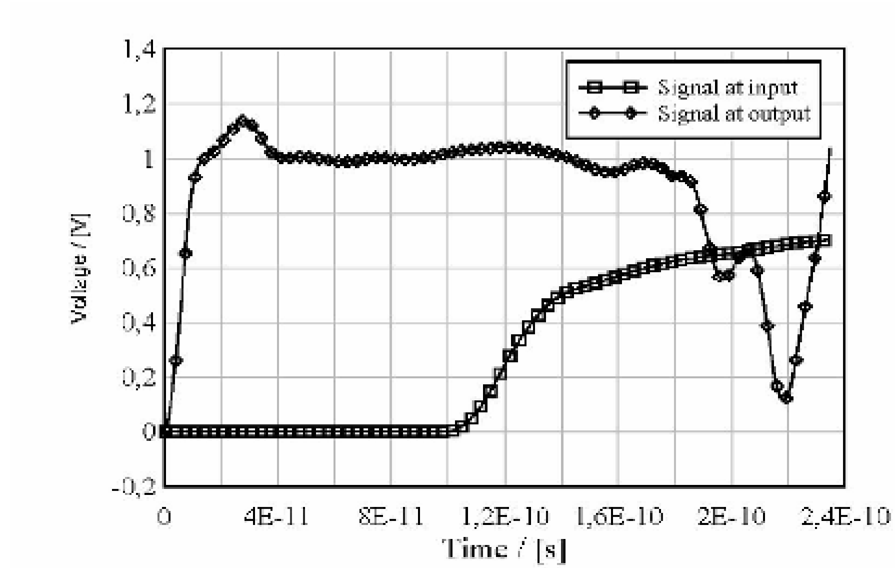
Iterative Bi-section approach for domain decomposition & Load balancing

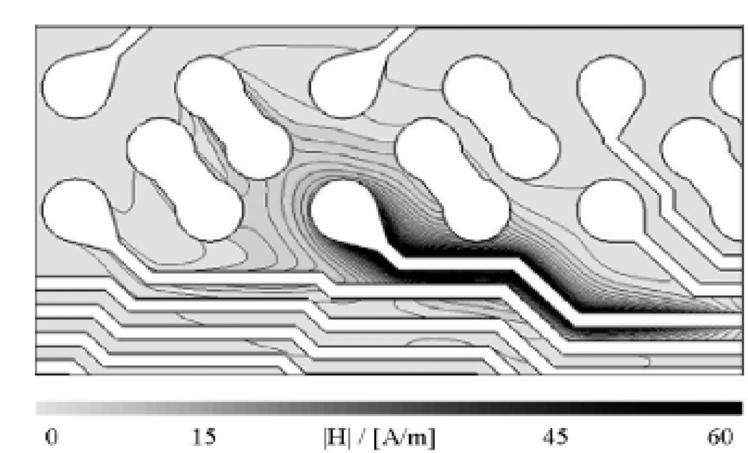
Ref: E P Li, et al, JEMAP, 2004, EPEP, 2006

Results



CPU Time spent vs Processors





Magnetic field distribution at layer FC3

Ref: E P Li, et al, JEMAP, 2004, Y.J. Zhang, et al, IEEE Sym. 2007

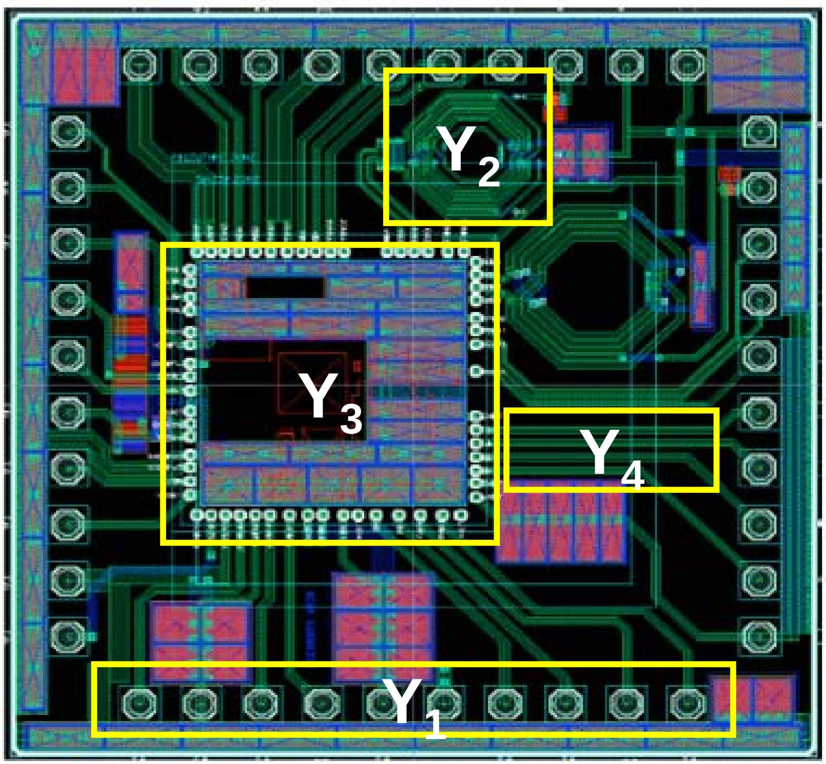
3 Modelling of Multilayered IC Packages

Recent Development

Semi-analytical Method

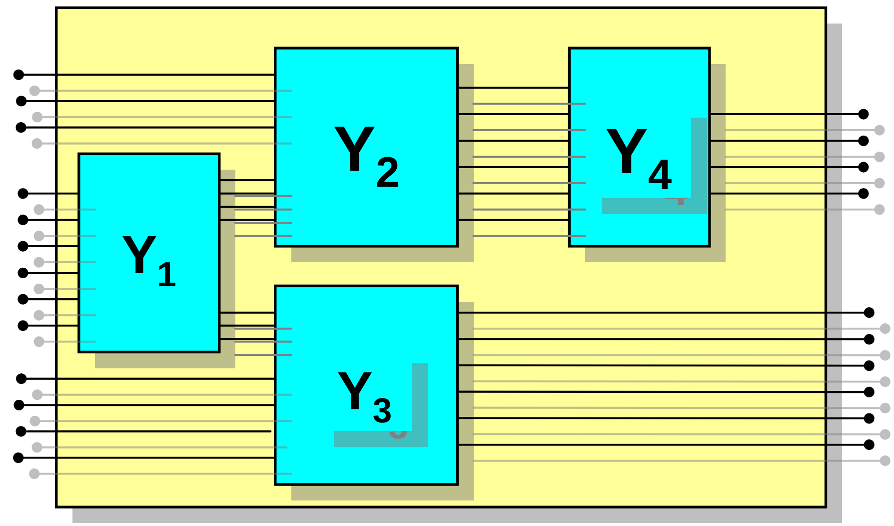
New Algorithm Development

Domain-Decomposition Approach



[Phillips]

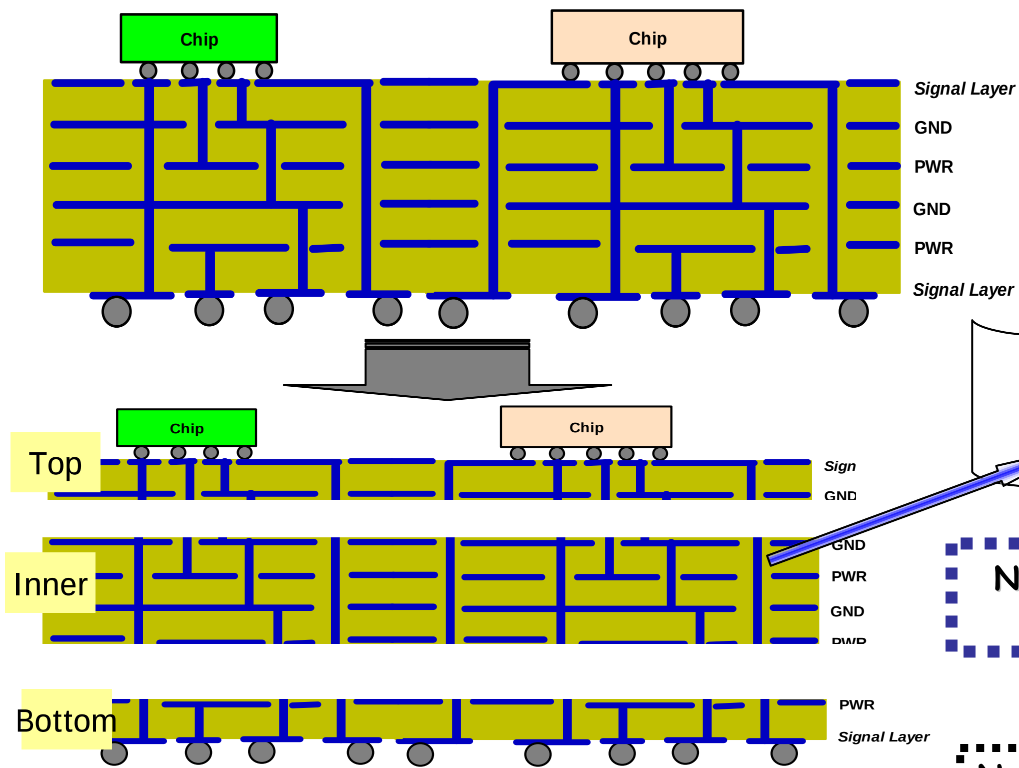
SIP (System in Package) on Silicon Carrier

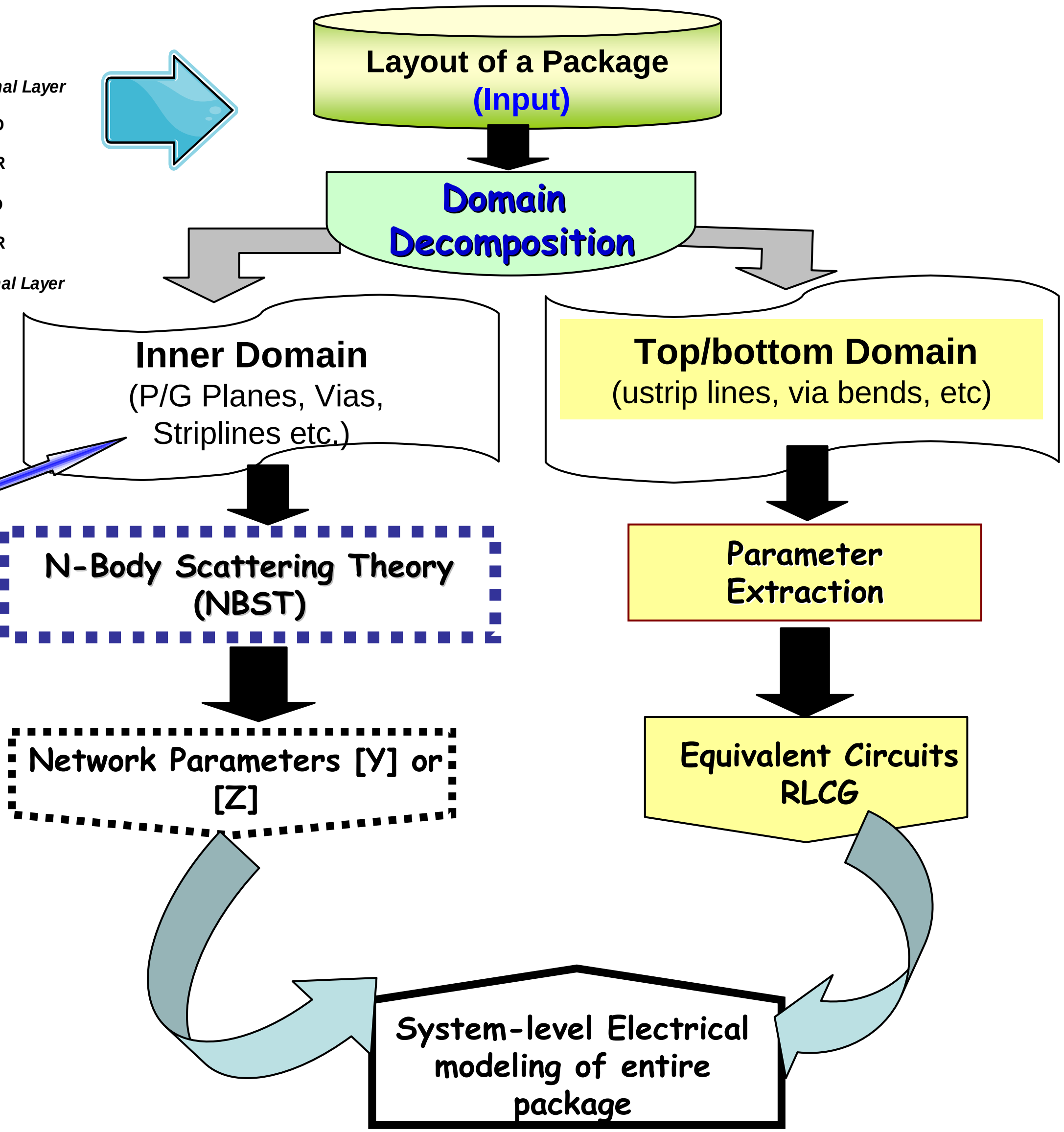


Domain-Decomposition

Different parts are modeled by using different optimized methodologies

Flowchart of Our Algorithm

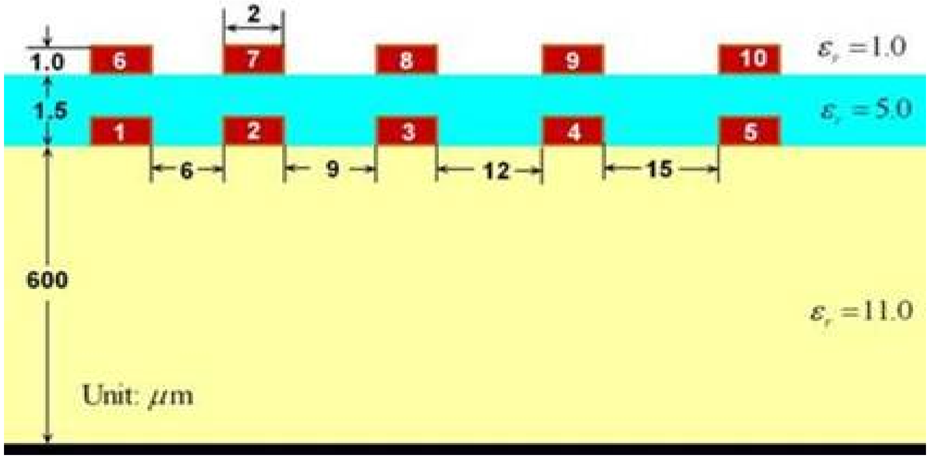


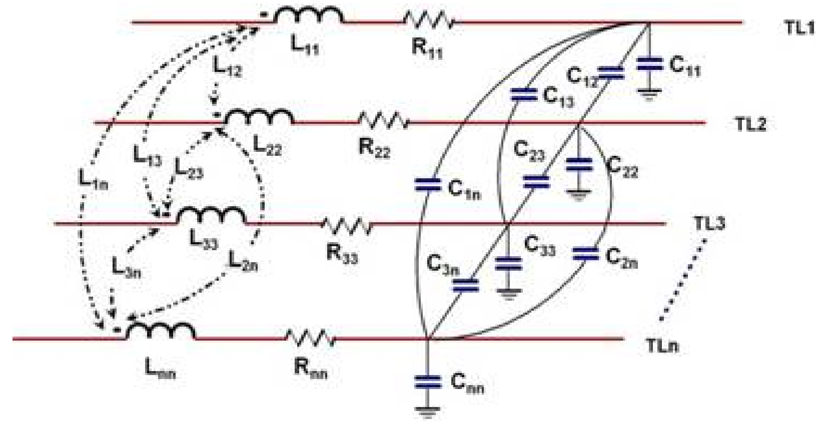


New Features of the Algorithm Compared to existing techniques

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

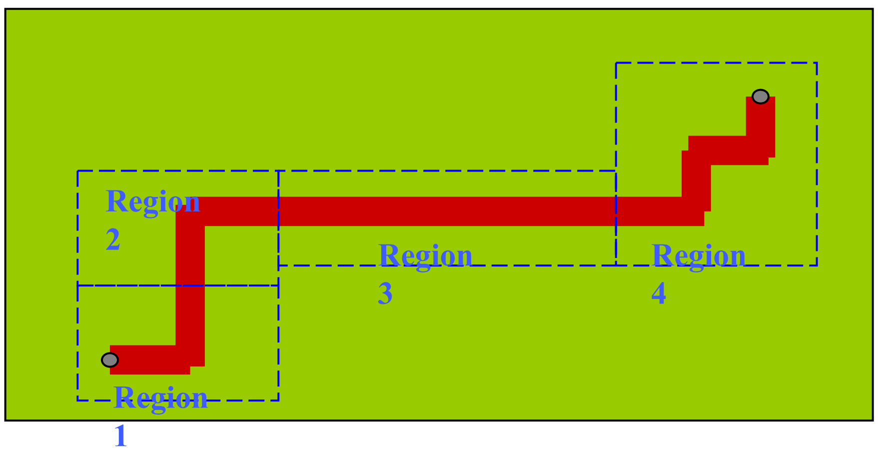
Modeling of Top/Bottom Domain

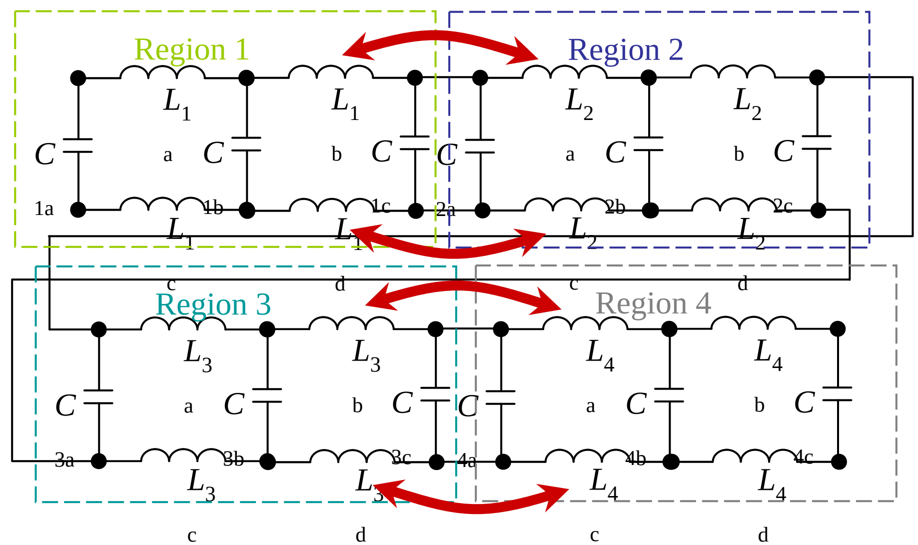




Integral Equation Method

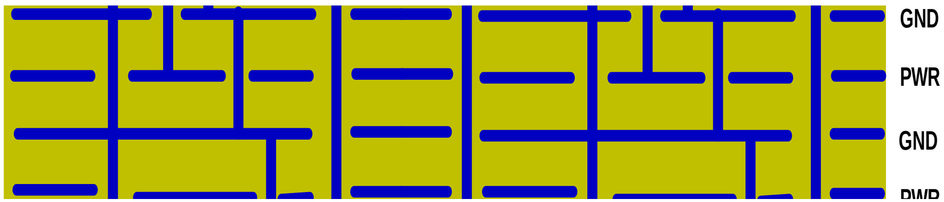
Equivalent Circuits





[Er-Ping LI, En-Xiao Liu et. al, IEEE EMC Symposium 2007]

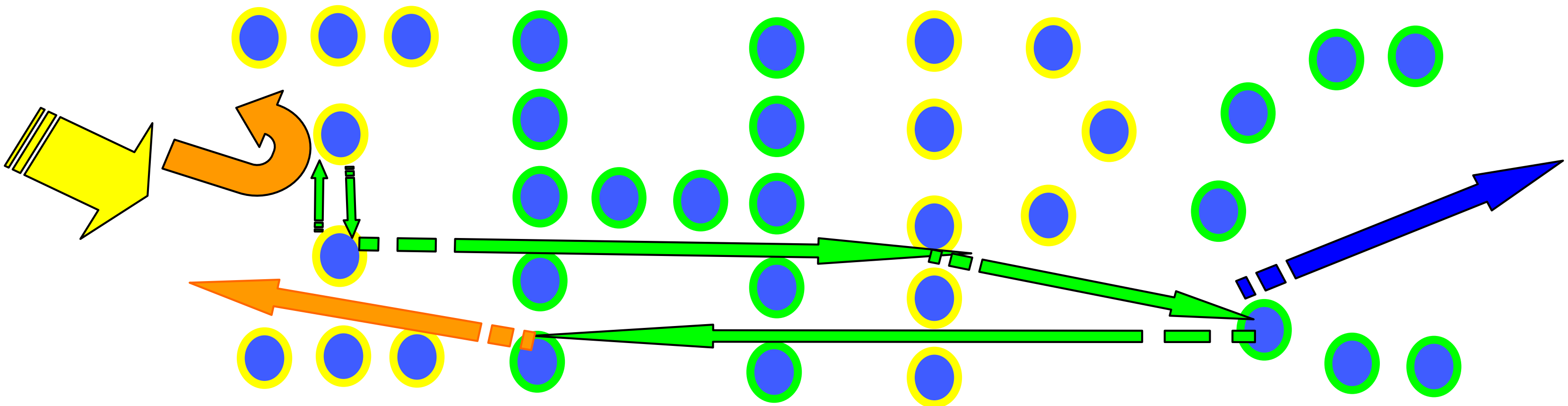
Modeling of Inner Domain



N-Body Scattering Theory (NBST)

for analyzing coupling among multiple vias in the presence of multilayered P/G planes

Superposition: $\mathbf{E}^{total} = \mathbf{E}^{inc} + \mathbf{E}^{scat(multiple)}$



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

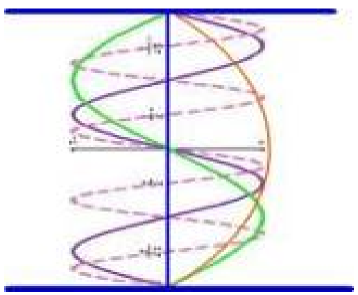
Modal Expansion

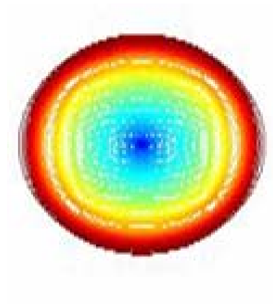
TE & TM Modes

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.

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

Cylindrical Mode (CYM)
-- Vias





$$E_z = \sum_m \sum_n a_{mn}^E \cos(k_m z) Z_n(k_\rho \rho) e^{jn\phi} \quad \text{for TM}$$

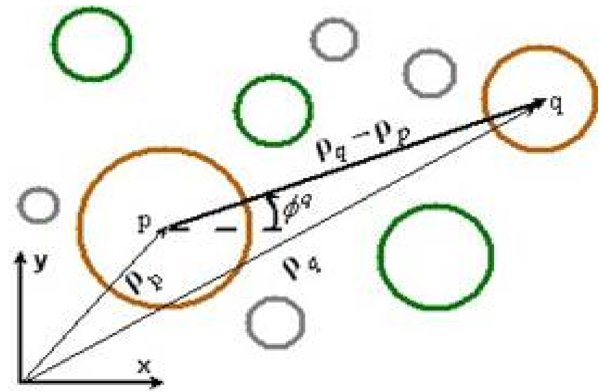
$$H_z = \sum_m \sum_n a_{mn}^H \cos(k_m z) Z_n(k_\rho \rho) e^{jn\phi} \quad \text{for TE}$$

[Z. Z. Oo, En-Xiao LIU et. al, ECTC 2007]

Multiple Coupling among Large Number of Vias

Scattering among N Vias

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



Scattered fields

Coefficients of the incident wave (excitation)

$$\boldsymbol{f}_q = \bar{\mathrm{T}}_q \left(\boldsymbol{a}_q + \sum_{p=1;\, p\neq q}^{N_{via}} \bar{\boldsymbol{\alpha}}_{qp}\, \boldsymbol{f}_p \right)$$

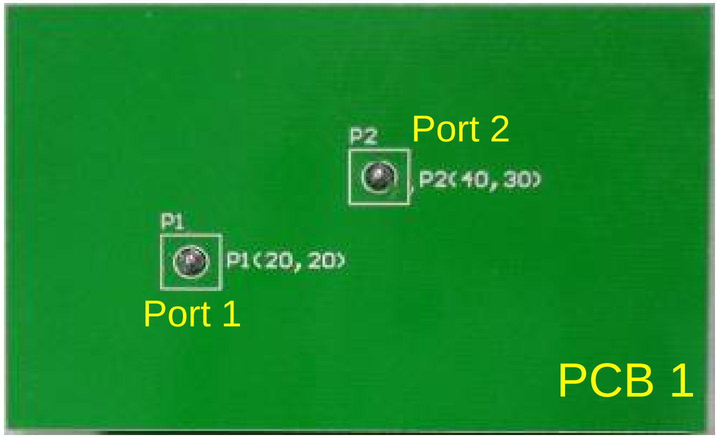
Unknown coefficients of the scattered wave

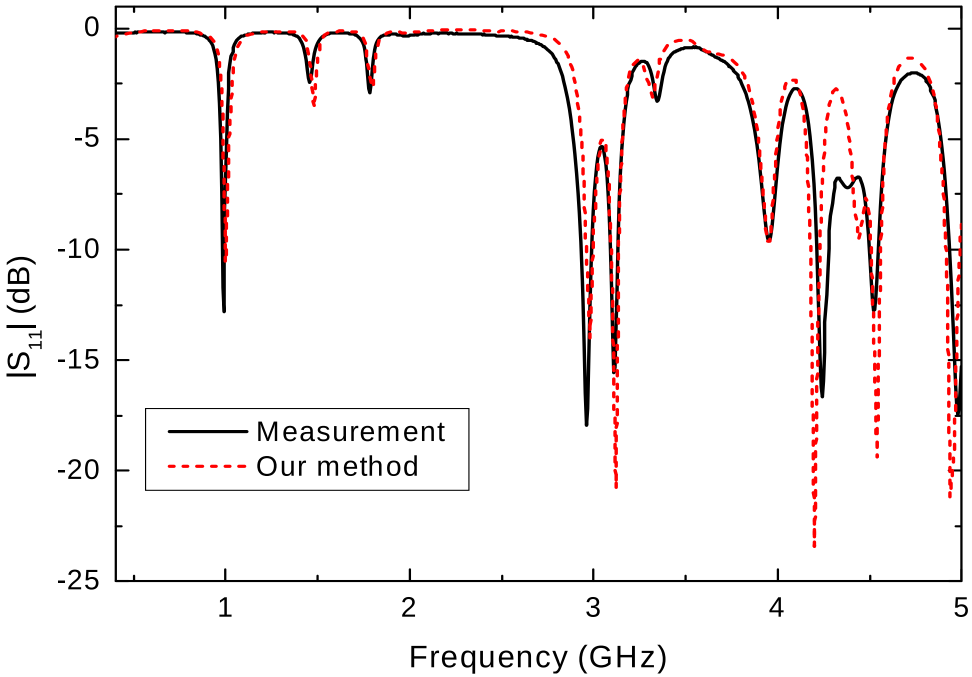
T (transition) Matrix

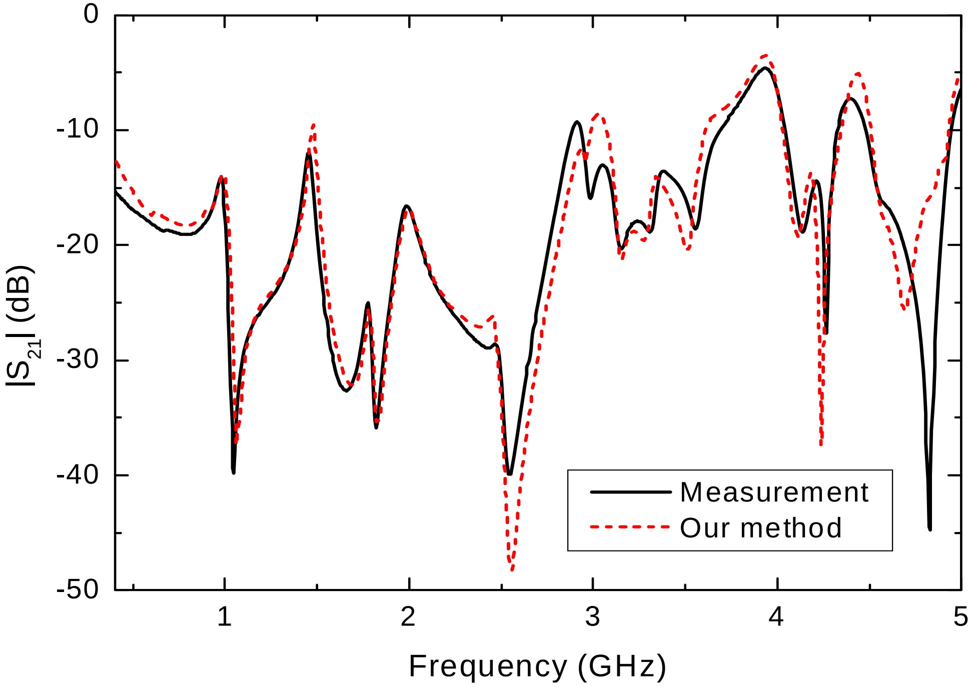
Translation Matrix

Experimental Validation

- Test board 2:
  - two SMA ports (signal vias)
  - thickness 1 mm
  - via diameter 0.1 mm
  - substrate material 4.1; loss tan 0.02

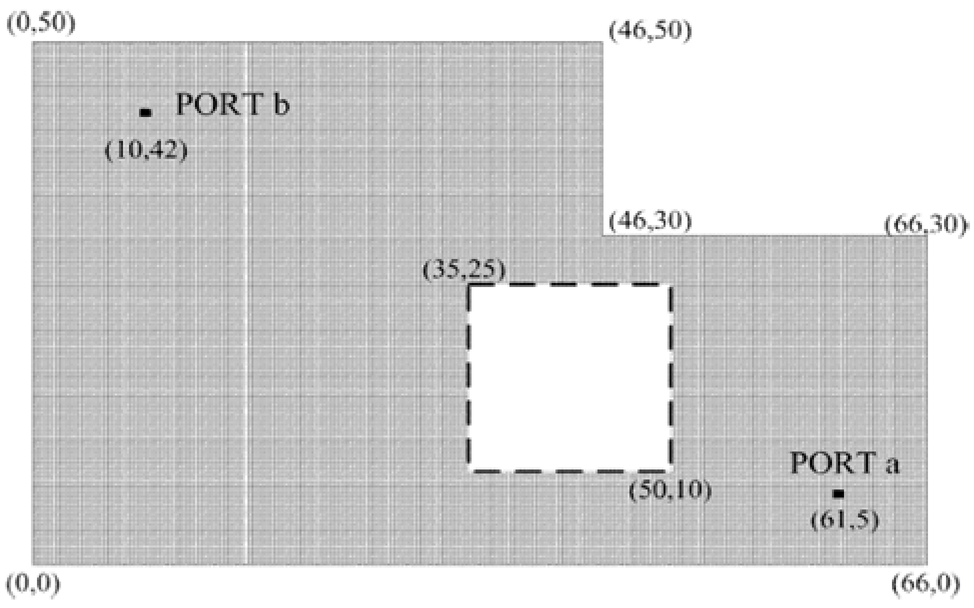




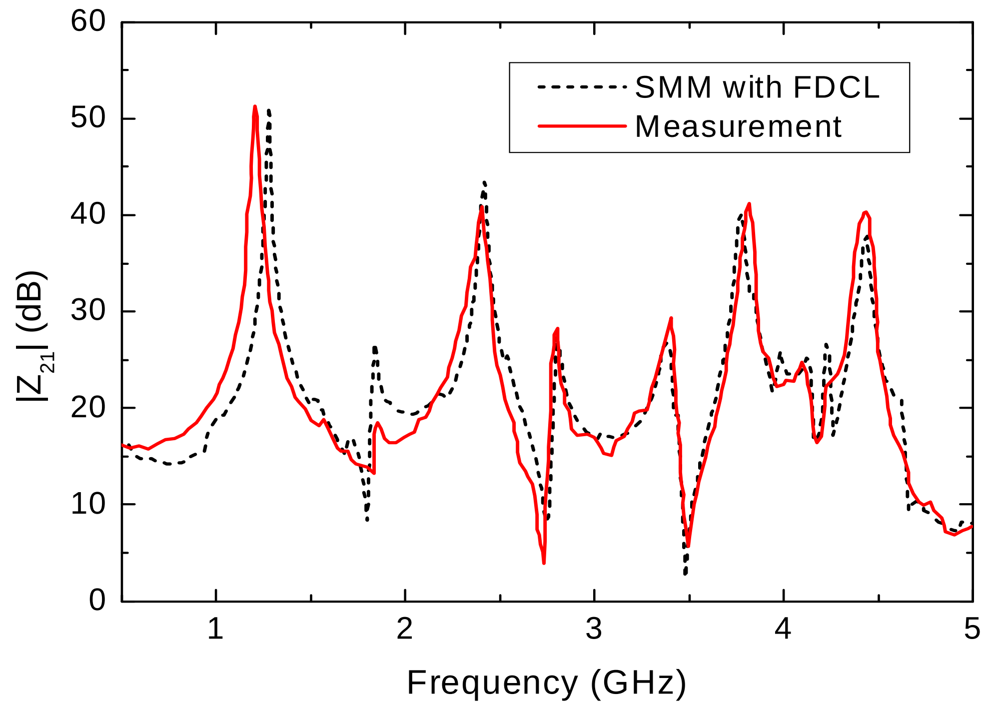


Validation: L-shaped P/G Plane and Cut-out Structure

- 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



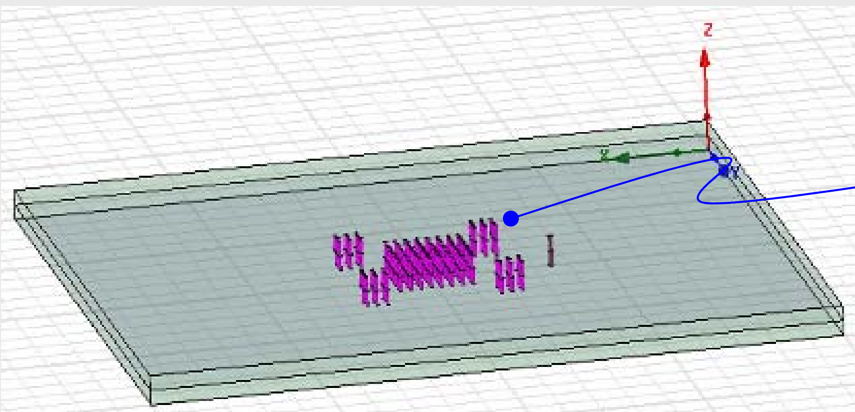
Unit: mm

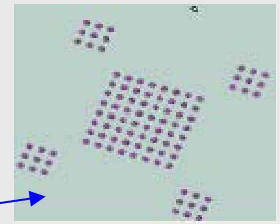


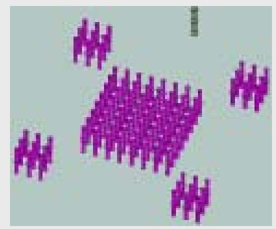
Measurement Ref.: Ping Liu et al, IEEE Trans EMC, vol. 47, no. 4, pp. 889-898.

Comparison against Ansoft HFSS

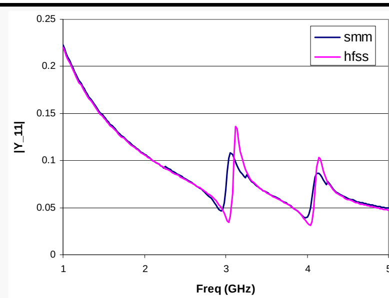
101 pins (vias) in three power/ground layers

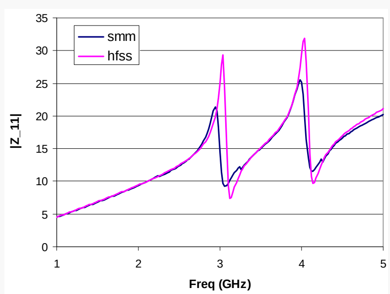


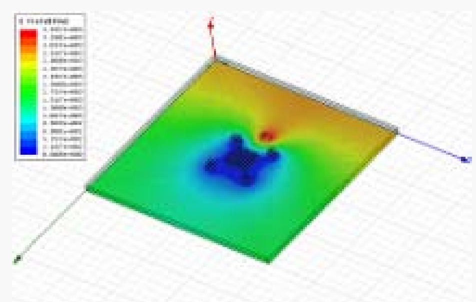




- 101 Pins (PEC vias)
- Three conductor layers (P/G/P) & 0.8-mm total thickness
- 20 x 20 mm dimension







Comparison against Ansoft HFSS

No. of power/ground layers	No. of vias (pins)	Memory		CPU time	
		HFSS	Our Approach	HFSS	Our Approach
2	2	20 MB	6 MB	10min 50 sec	43 sec
	101	138 MB	43MB	77min 51sec	14min 57sec
3	101	420 MB	140MB	320min 29sec	20min 14sec
	221	Out of memory	500MB	N.A	135min 53sec
4	2	50 MB	15 MB	13min 50sec	3min 21sec

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

Outlook and Summary

- 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.

Outlook and Summary

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.
-

Outlook and Summary

- **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.

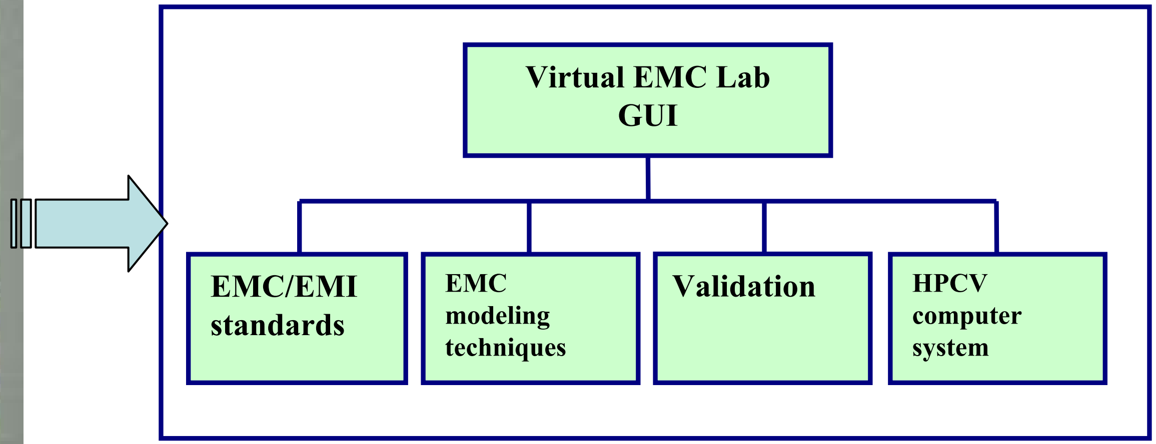
Outlook and Summary

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

Conventional EMC testing house



Virtual EMC Lab

Thank you for your attention!