MoM and PEEC Method to Reach a Complete Equivalent Circuit of a Static Converter





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Models for Power Interconnections

3. Adaptive Multi-Level Fast Multipole Method

Objectives



- » accelerate the computation of interactions >> few memory consuming
- Theory of interactions >> multipole approach with spherical harmonics

 $Y_{n}^{m}(\theta,\phi) = \sqrt{\frac{(n-|m|)!}{(n+|m|)!}} P_{n}^{|m|}(\cos\theta) e^{im\phi}$ Legendre polynomial

>> possible interactions on an example



Principal of the adaptive multi-level >> interaction control by an octree >> cube partitioning of the geometry

Performances

- >> time integration and resolution comparisons on 2 parallel plates more and more meshed
- \rightarrow a problem with 10,082 elements requires 3Gb of memory to solve \rightarrow computation speed is highly

Q2M: charge to multipole $(M_n^m) = \sum q_i Y_n^{-m}(\alpha_i, \beta_i) \rho_i^n$ M2L: multipole to local $\underbrace{L_{j}^{k}}_{j} = \sum_{n}^{m} \sum_{k=1}^{n} K_{jn}^{km} \underbrace{M_{n}^{m}}_{n} \underbrace{Y_{j+n}^{m-k}(\alpha,\beta)}_{j}$ n=0 m=-nL2P: local to potential $(\Phi(P)) = \sum \sum (L_j^k) Y_j^k(\theta, \phi) . r^j$ j=0 k=-j $\vec{E}(P) = -\vec{\nabla} \Phi(P)$ $\vec{E}(P) = -\sum_{k=1}^{+\infty} \sum_{j=1}^{j} L_{j}^{k} \vec{\nabla} (Y(\theta, \phi).r^{j})$







increased with AMLFMM



Total mesh numbe

Parasitic Capacitance Computation

1. Integral Method

- Problem hypothesis
 - >> 0-order Galerkin approach (constant charge) >> Point matching method (mesh center points) >> Numerical integration (Gauss method) >> Analytical correction for the diagonal

Mesh of interfaces

>> diel.-air, diel.-cond., cond.-air >> triangle or quadrangle elements >> conformal mesh is not required

conductor

Electric potential conductor / dielectric interface



Electric potential coefficients

* *m* = number of conductor regions



dielectric

Normal electric field *dielectric / dielectric interface*



→ Normal electric field coefficients



Application to Boost Converters



35µm-thick copper tracks 1,6mm-thick epoxy

ground plane : 28mm under tracks

1. (R-L-M-C) Circuit Extraction

- Inductive matrix [R-L-M]
 - >> Inductive mesh in the skin depth (1MHz)
 - PEEC method (InCa3D[®])
- Capacitive matrix [C]
 - >> Capacitive mesh : 7,000 quadrangle elements
 - >> Integral method with point matching method
 - \rightarrow Computation validation : measurement and FEM computation (Flux3D[®])

Capa. (p⊦)	C17	C27	C37	C47	C57	C67	C12	C23	C34	C53	C65	C16
Mes.	1,53	1,25	2,95	0,87	6,5	1,57	0,92	0,7	1,12	1,26	0,93	0,98
МоМ	1,77	1,3	2,72	0,88	5,28	1,72	0,34	0,08	0,89	1,36	0,38	0,49
FEM	1,9	1,4	2,92	0,93	5,67	1,84	0,25	0,06	0,8	1,1	0,27	0,4
% MoM/Mes.	15,7	4,0	7,8	1,1	18,8	9,6	63,0	88,6	20,5	7,9	59,1	50,0
% FEM/Mes.	24,2	12,0	1,0	6,9	12,8	17,2	72,8	91,4	28,6	12,7	71,0	59,2

Sketch of the Topology :









Building complete (R-L-M-C) Circuit >> Capacitance location : discretization of conductors to accurate capacitive effect computations

2. Radiated EMC modeling

- Modeling of common and differential mode current and voltage excitations >> FFT of currents and voltages (Saber[®])
- Study of Electric Far Field >> Modeling : magnetic far field B (InCa3D[®]) and computation of electric field E (wave impedance)
 - » Measurement in anechoic chamber : 3m electric field in a plane perpendicular to copper tracks





importance of an accurate capacitive modeling \rightarrow

 \rightarrow a real variable speed drive has been modeled (confidential results)