Introduction

HFSS
3D EM Analysis
S-parameter

Q3D
R/L/C/G Extraction
Model
Quasi-static or full-wave techniques

- Measure the size of the interconnect in units of wavelength!

  - Size < $\lambda/10$, use quasi-static solvers. Output circuit model in RLG.
  - Size > $\lambda/10$, and/or radiation important, use full-wave solvers. Output S, Y, and Z parameters and fields.
Wavelength issues

- low frequencies (lump model): $\lambda/10$ wavelengths $>>$ wire length

$\nu_p = \lambda \times f$

100MHz  2GHz  8GHz
Q3D Extractor

1. 3D Fast Quasi-static EM solver

2. 2D Fast R/L/C/G EM solver
The equation relating the total charge on a capacitor with the potential difference relative to a ground at zero volts is: $Q = CV$

In a three-conductor system, matrix notation is used:

$$
\begin{bmatrix}
Q_1 \\
Q_2 \\
Q_3
\end{bmatrix} =
\begin{bmatrix}
C_{11} & C_{12} & C_{13} \\
C_{21} & C_{22} & C_{23} \\
C_{31} & C_{32} & C_{33}
\end{bmatrix}
\begin{bmatrix}
V_1 \\
V_2 \\
V_3
\end{bmatrix}
$$

The off diagonals are always negative, which accounts for the sign of the charge on each of the conductors.
Q3D and circuit capacitance

Q3D solution:

\[
\begin{bmatrix}
Q_1 \\
Q_2
\end{bmatrix} =
\begin{bmatrix}
C^{s}_{11} & C^{s}_{12} \\
C^{s}_{21} & C^{s}_{22}
\end{bmatrix}
\begin{bmatrix}
V_1 \\
V_2
\end{bmatrix}
\]

circuit solution:

\[
Q_1 = C^k_{11} V_1 + C^k_{12} (V_1 - V_2) \\
Q_2 = C^k_{21} (V_2 - V_1) + C^k_{22} V_2
\]

\[
C^{s}_{11} = C^k_{11} + C^k_{12} \\
C^{s}_{12} = -C^k_{12}
\]
Self-inductance

$V = L \frac{dI}{dt}$

wire carrying a current

paper screen with iron filings sprinkled

photo source: Halliday and Resnick, Physics, 1962
Mutual-inductance

A voltage is induced across a conductor when the number of field lines around it changes.

\[ V = L_s \frac{dI_a}{dt} + L_{ab} \frac{dI_b}{dt} \]
Partial inductance

- Partial self inductance: number of field lines per amp around just the conductor segment.
- Partial mutual inductance: number of field lines per amp around both the conductor segment.

\[ \psi = \int \vec{A} \cdot d\vec{l} \]

\[ \vec{A} = 0 \text{ for } \vec{A} \]
Partial inductance matrix

- Defined for any collection of conductors

\[ V_j = \sum_k L_{jk} \frac{dI_k}{dt} \]

\[ V_1 = L_{11} \frac{dI_1}{dt} + L_{12} \frac{dI_2}{dt} + L_{13} \frac{dI_3}{dt} + L_{14} \frac{dI_4}{dt} \]

Partial self inductance
Partial mutual inductance
Loop inductance

\[
V_2 = L_{22} \dot{I}_2 + L_{21} \dot{I}_1 + L_{23} \dot{I}_3 + L_{2g} \dot{I}_g
\]

\[
V_{gnd} = L_{gg} \dot{I}_g + L_{g1} \dot{I}_1 + L_{g2} \dot{I}_2 + L_{g3} \dot{I}_3
\]

\[
V_2' = V_2 - V_{gnd}
\]

\[
V_2' = \dot{I}_1 (L_{21} - L_{2g} - L_{g1} + L_{gg})
+ \dot{I}_2 (L_{22} - L_{2g} - L_{g2} + L_{gg})
+ \dot{I}_3 (L_{23} - L_{2g} - L_{g3} + L_{gg})
\]
The individual elements of the inductance matrix are computed in the same way as the elements of the capacitance matrix.

For a three-conductor system with a well-defined ground return path, the relationship between the magnetic flux in each loop and the current loop I in each is given by:

\[
\begin{bmatrix}
\Phi_1 \\
\Phi_2 \\
\Phi_3
\end{bmatrix} = \begin{bmatrix}
L_{11} & L_{12} & L_{13} \\
L_{21} & L_{22} & L_{23} \\
L_{31} & L_{32} & L_{33}
\end{bmatrix} \begin{bmatrix}
I_1 \\
I_2 \\
I_3
\end{bmatrix}
\]

The diagonal elements are self-inductances and the symmetric off-diagonal elements are the mutual inductances of the loops.
Solve setup

- Capacitance matrix
- DC Resistance and inductance matrix
- AC Resistance and inductance matrix
Solve setup

- Number of conduction passes to refine FEM mesh
- % total error as stopping criteria
- % with the largest error, changed per pass

![Image of software interface showing settings for solve setup, including options for conduction and multipole adaptive solutions with maximum number of passes, percent error, and percent refinement per pass.]
Solve setup

Conduction passes. C: optimizes DC mesh

Difference between the n and n-1 iteration

M: calculate the R, L and optimizes the large scale structure of the mesh
Mesh of DC and AC solution
Reduced matrix operation

- Move sink
- Add sink
- Join in series
- Join in parallel
- Float net
- Return path
- Ground net
- Float terminal
- Float at infinity
- Change frequency
Move sink

Let you switch the placement of sink terminals in a conductor without having to change the terminal assignment and generate a new solution.

\[ i_{out} = i_1 + i_2 + i_3 \]
Add sink

- Allow user to add current sinks to a model without having to change the setup and generate a new solution.
- Allows user to simulate the presence of multiple current sinks in a conductor. While actually solving the model, only a single sink is allowed for conduction simplicity.
Join in series and parallel

- This feature allows you to connect two or more conductors in series and parallel.

**Series**

\[ i_1 + i_2 + i_3 \]

**Parallel**

\[ i = i_2 + i_3 \]
Ground net and Return path

- Grounded net reduce feature allows you to add grounded conductors to your model.
- Return path lets you select a conductor that is identified as a return path enabling you to model the effects of return currents on the inductance and resistance matrices.

Notice that the negative reference node for defining the branch voltages has also been changed.
Q3D extractor processes

1. Parametric Model
   Geometry/Materials

2. Analysis
   Solution Setup

3. Results
   2D Reports
   Matrix Reduction Fields

4. Solve Loop
   Mesh Refinement
   Solve
   Converged
   NO
   YES
   Finished

1.1 Excitations
   src/snk

Design

Update
Reference
