ANSOFT Q3D TRANING

Introduction

HFSS

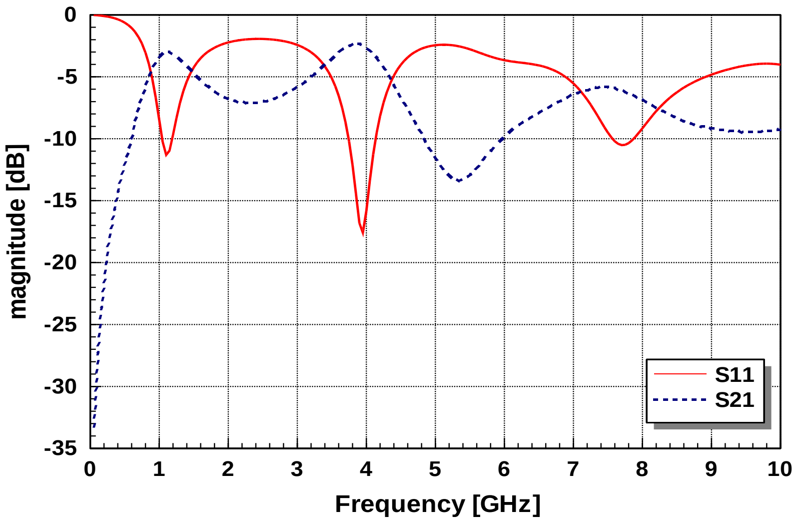
3D EM Analysis

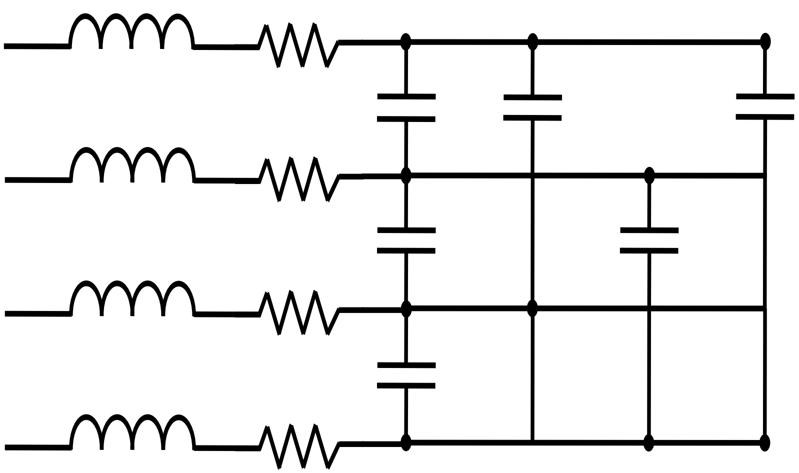
S-parameter

Q3D

R/L/C/G Extraction

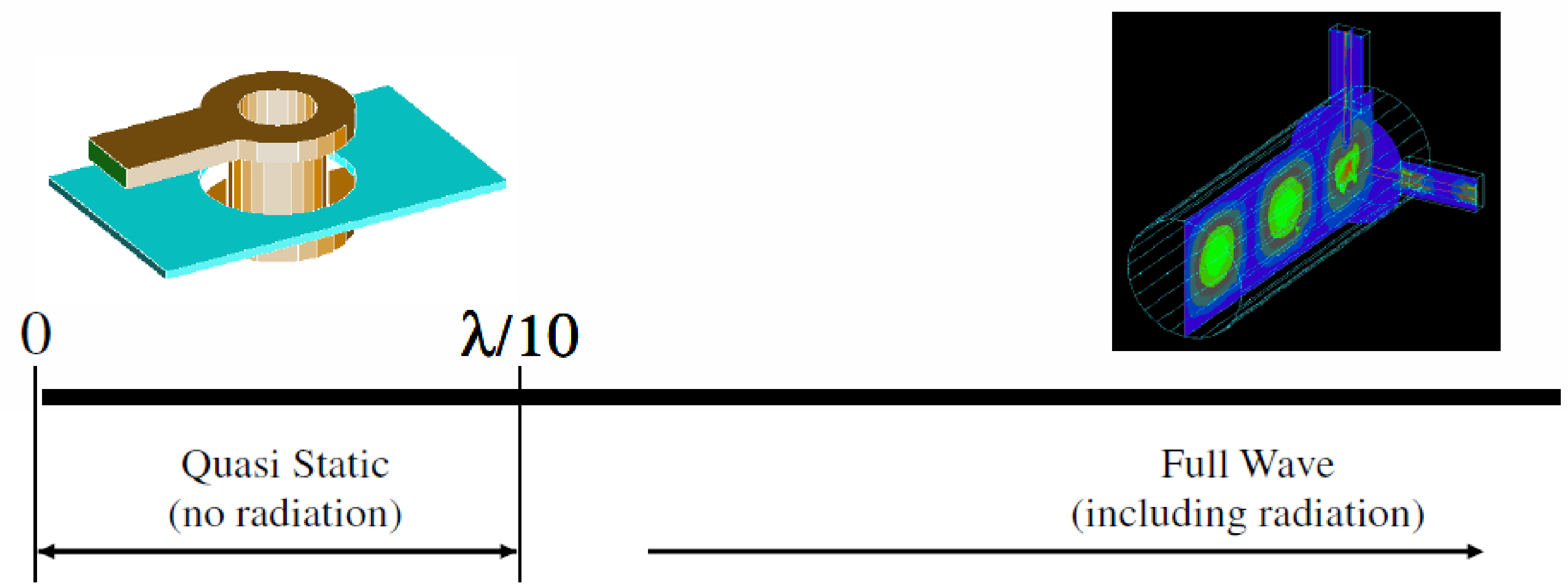
Model





Quasi-static or full-wave techniques

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

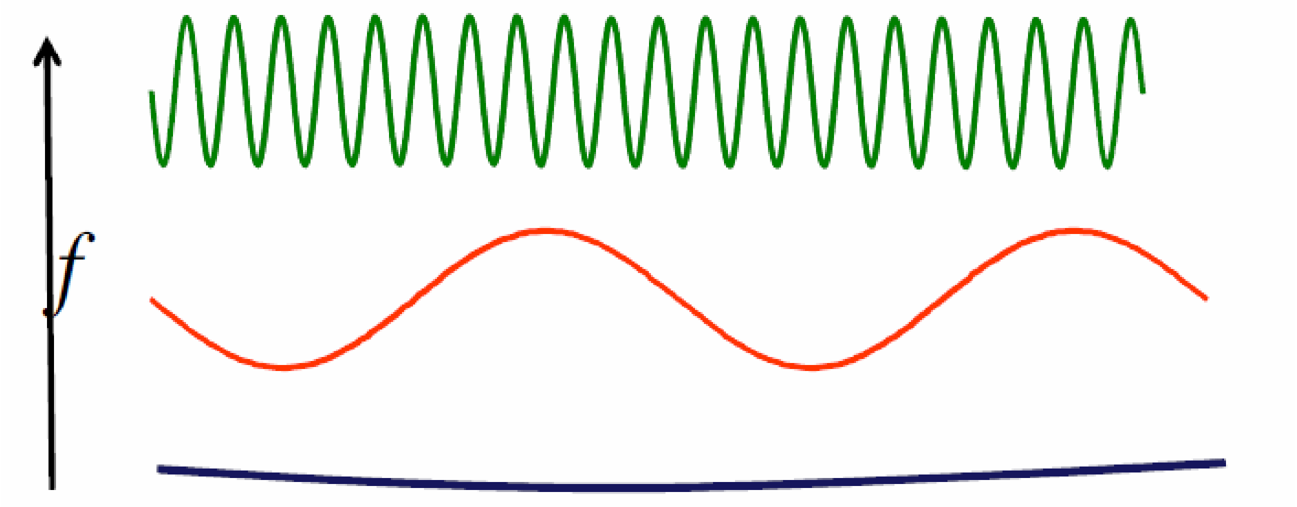


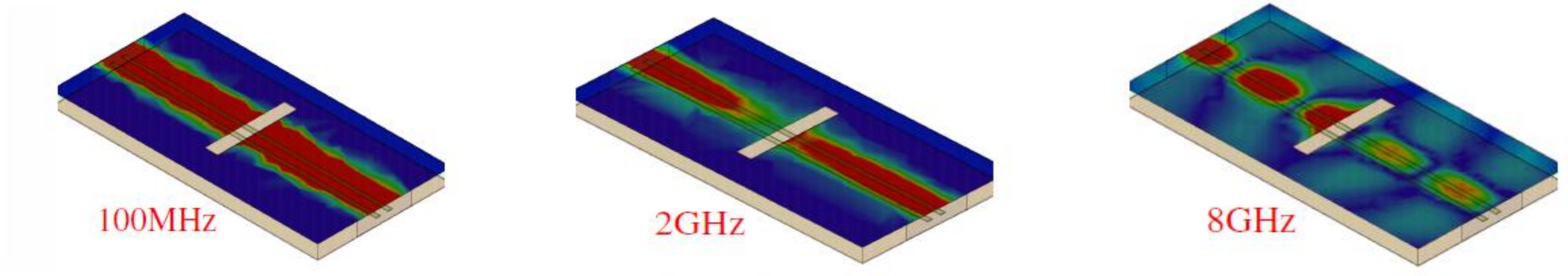
- Size < $\lambda/10$, use quasi-static solvers. Output circuit model in RLGC.
- Size > $\lambda/10$, and/or radiation important, use full-wave solvers. Output S, Y, and Z parameters and fields.

Wavelength issues

- low frequencies (lump model) : λ/10 wavelengths >> wire length

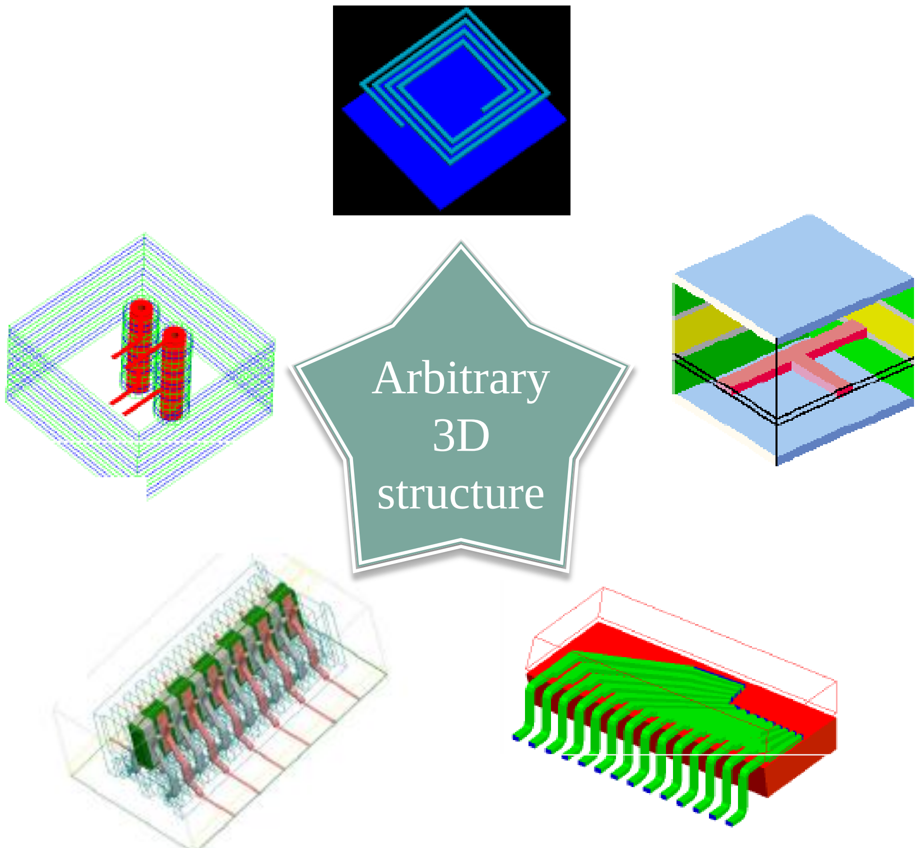
$$v_p = \lambda \times f$$



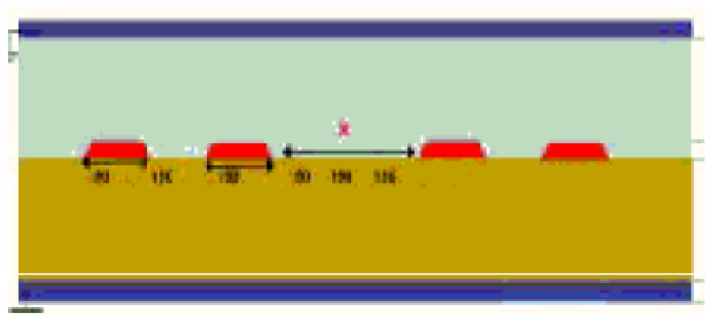


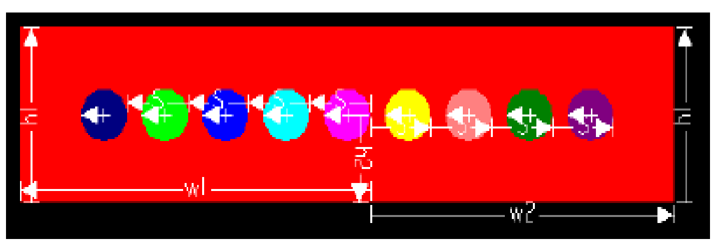
Q3D Extractor

1. 3D Fast Quasi-static EM solver



2. 2D Fast R/L/C/G EM solver



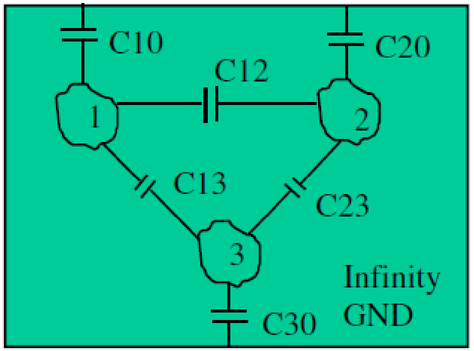


Capacitance matrix

- The equation relating the total charge on a capacitor with the potential difference relative to a ground at zero volts is : Q=CV

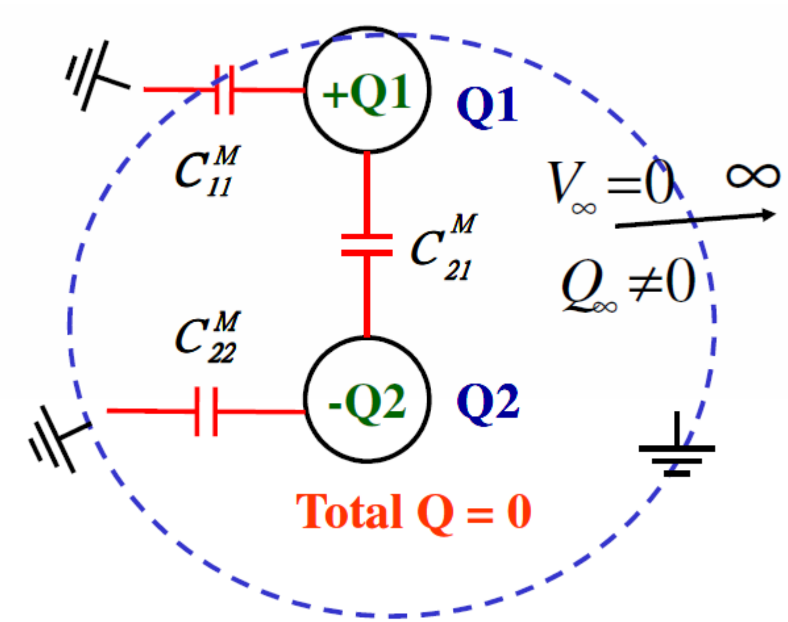
- In a three-conductor system, matrix notation is used:

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



- The off diagonals are always negative, which accounts for the sign of the charge on each of the conductors.

Q3D and circuit capacitance



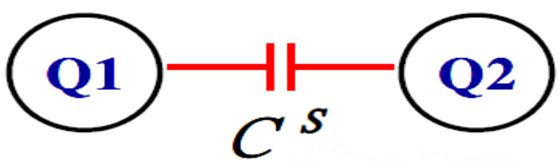
Q3D solution:

$$\begin{bmatrix} Q_1 \\ Q_2 \end{bmatrix} = \begin{bmatrix} C^s_{11} & C^s_{12} \\ C^s_{21} & C^s_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

circuit solution:

$$Q_1 = C^k_{11} V_1 + C^k_{12} (V_1 - V_2)$$

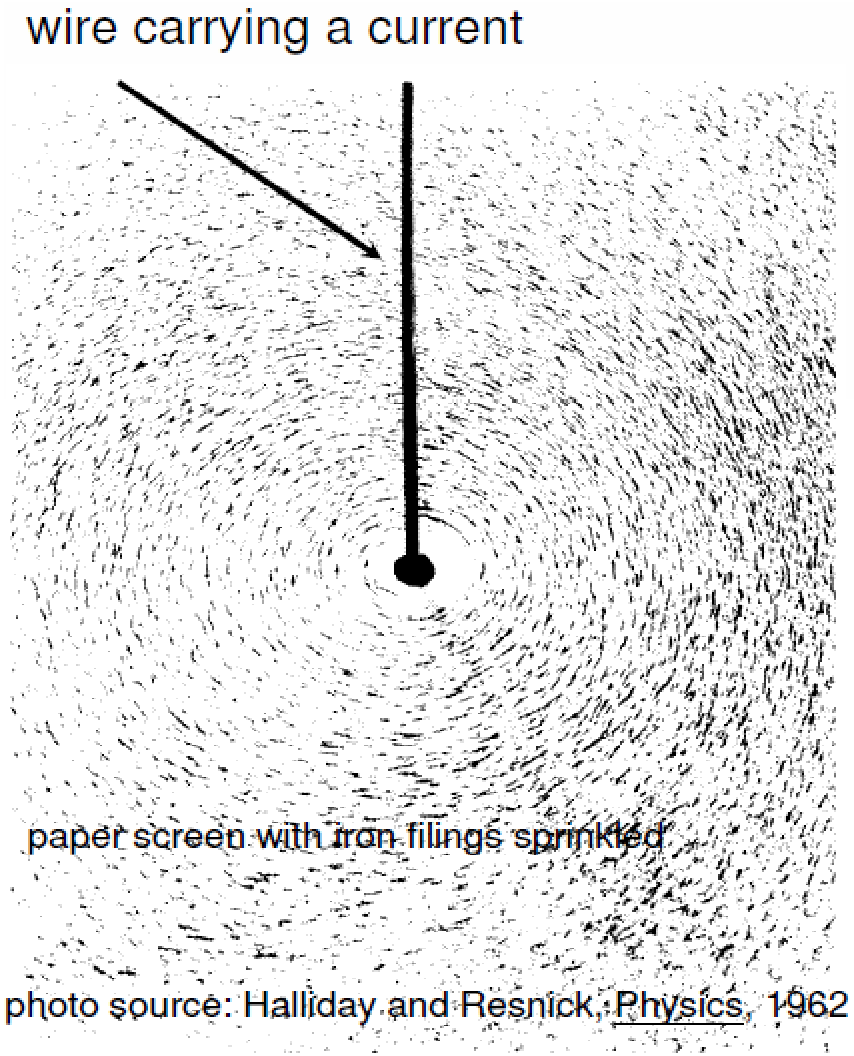
$$Q_2 = C^k_{21} (V_2 - V_1) + C^k_{22} V_2$$

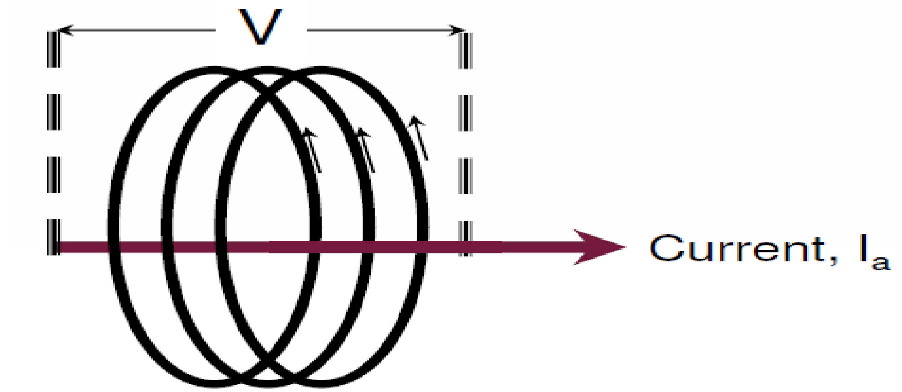


$$C^s_{11} = C^k_{11} + C^k_{12}$$

$$C^s_{12} = -C^k_{12}$$

Self-inductance

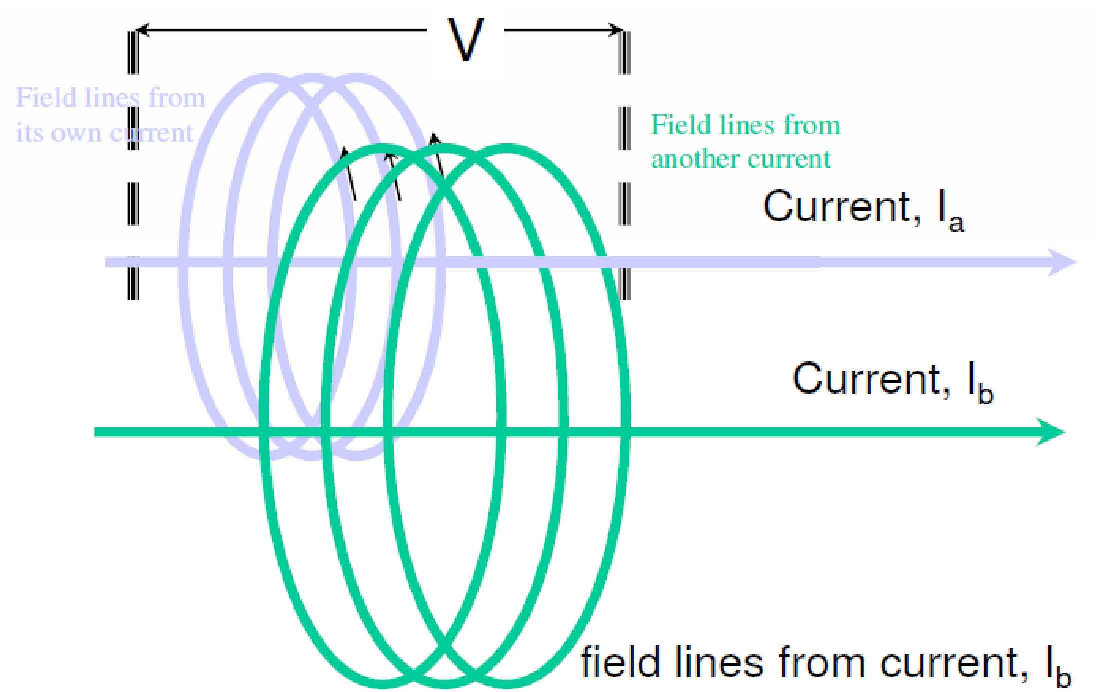




$$V = L\frac{dI}{dt}$$

Mutual-inductance

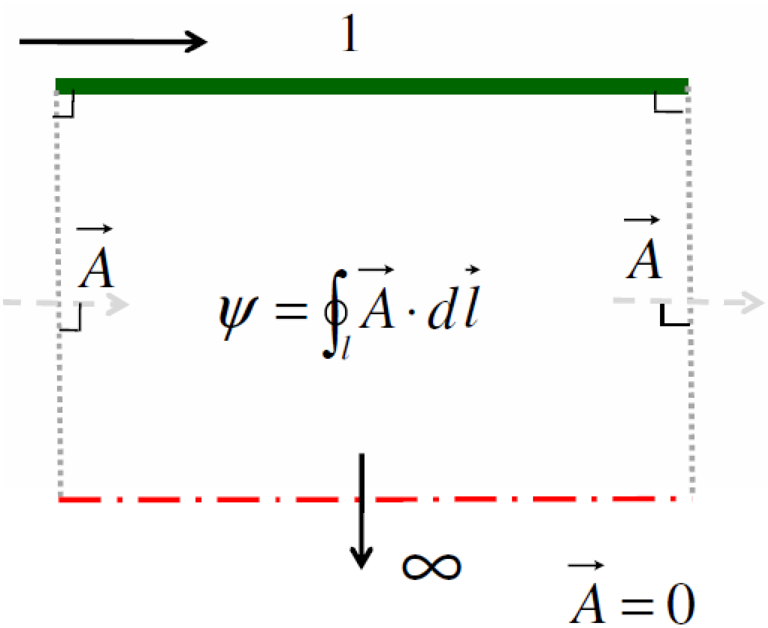
- A voltage is induced across a conductor when the number of field lines around it changes.



$$V = L_s \frac{dI_a}{dt} + L_{ab} \frac{dI_b}{dt}$$

Partial inductance

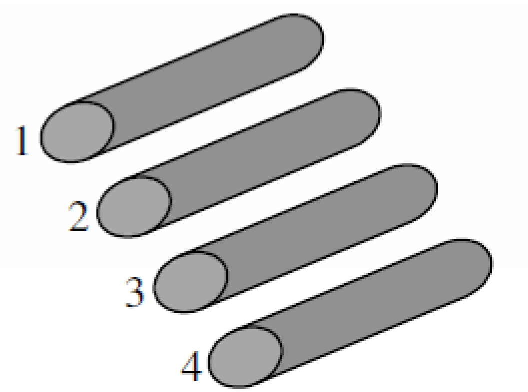
- Partial self inductance: number of field lines per amp around just the conductor segment.
- Partial mutual inductance: number of field lines per amp around both the conductor segment.



Partial inductance matrix

- Defined for any collection of conductors

$$V_j = \sum_k L_{jk} \frac{dI_k}{dt}$$

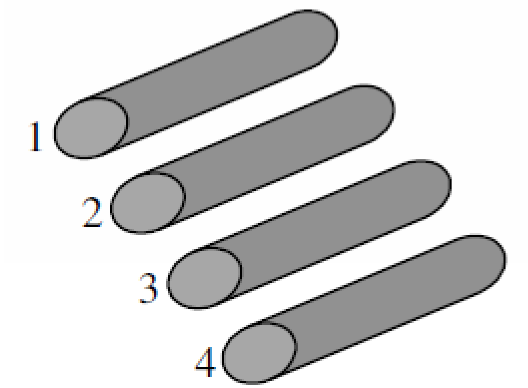


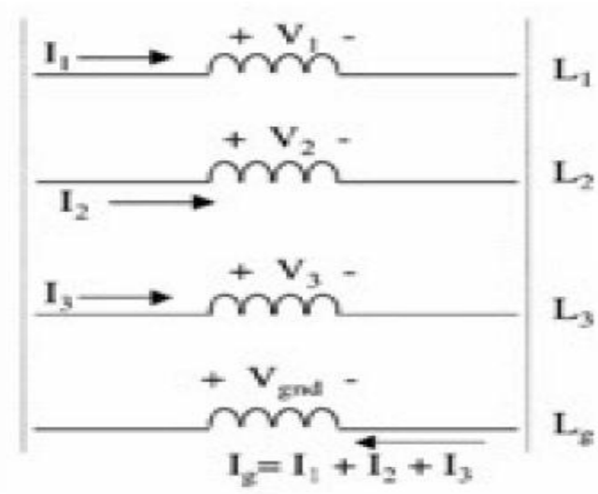
$$V_1 = L_{11}\frac{dI_1}{dt} + L_{12}\frac{dI_2}{dt} + L_{13}\frac{dI_3}{dt} + L_{14}\frac{dI_4}{dt}$$

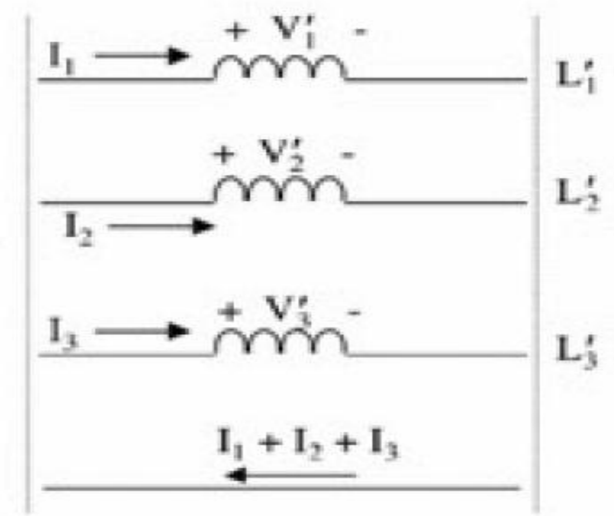
Partial self inductance

Partial mutual inductance

Loop inductance







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

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

$$V_2' = V_2 - V_{gnd}$$

$$\begin{aligned} V_2' = {} & \dot{I}_1(L_{21} - L_{2g} - L_{g1} + L_{gg}) \\ & + \dot{I}_2(L_{22} - L_{2g} - L_{g2} + L_{gg}) \\ & + \dot{I}_3(L_{23} - L_{2g} - L_{g3} + L_{gg}) \end{aligned}$$

Inductance matrix

- 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

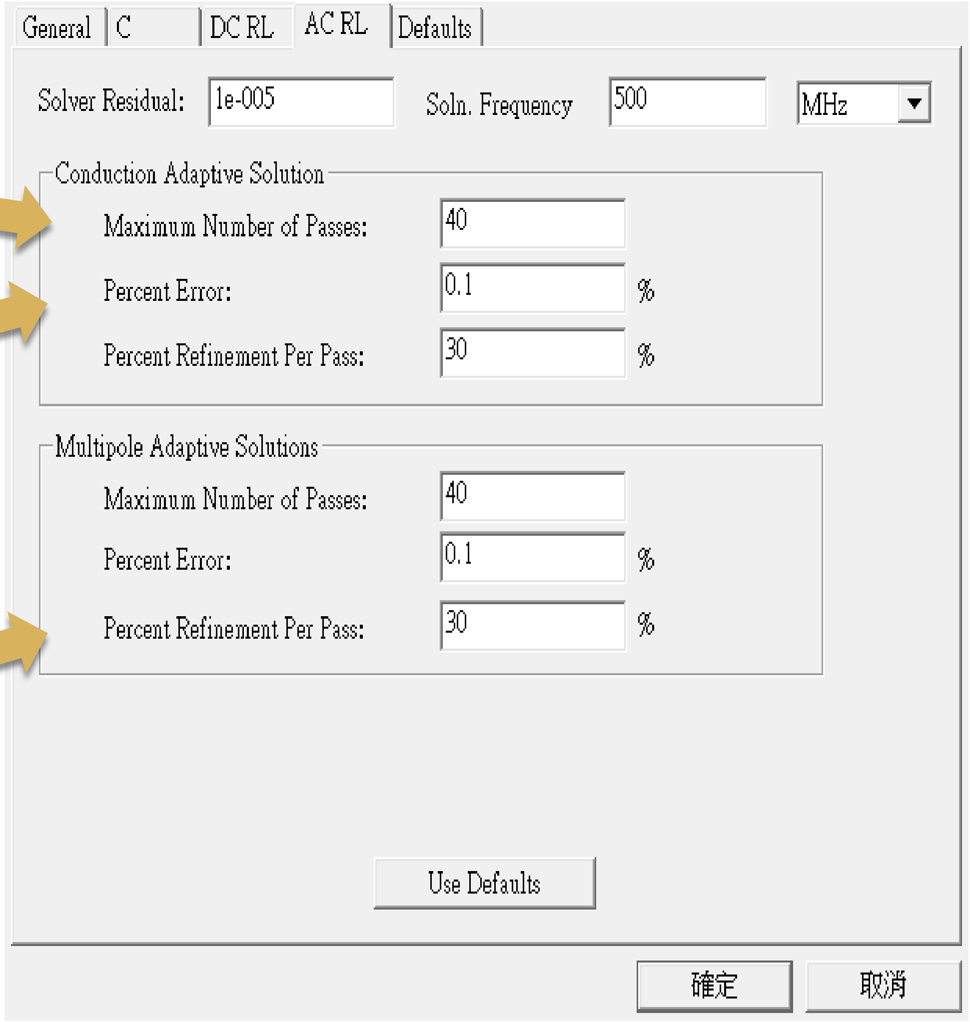
- Capacitance matrix
- DC Resistance and inductance matrix
- AC Resistance and inductance matrix

Solve setup

Number of conduction passes to refine FEM mesh

% total error as stopping criteria

% with the largest error, changed per pass

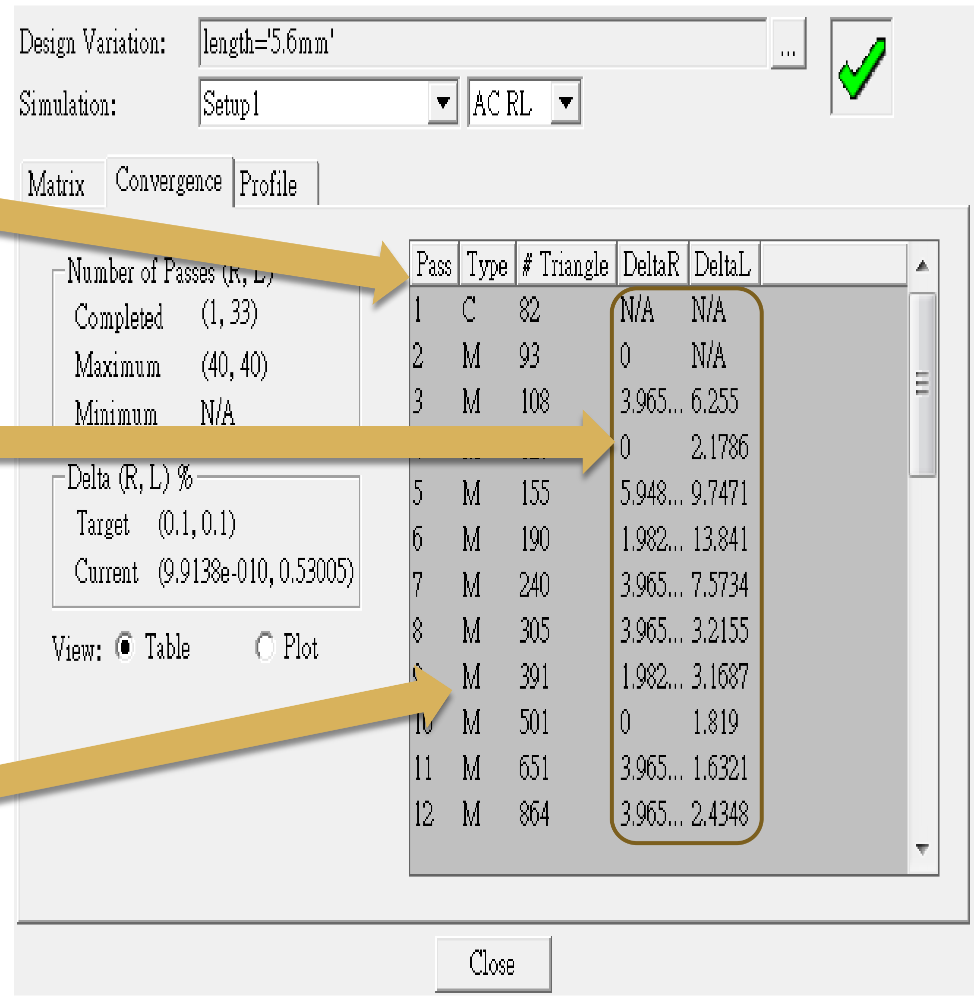


Solve setup

Conduction passes.
C: optimizes DC mesh

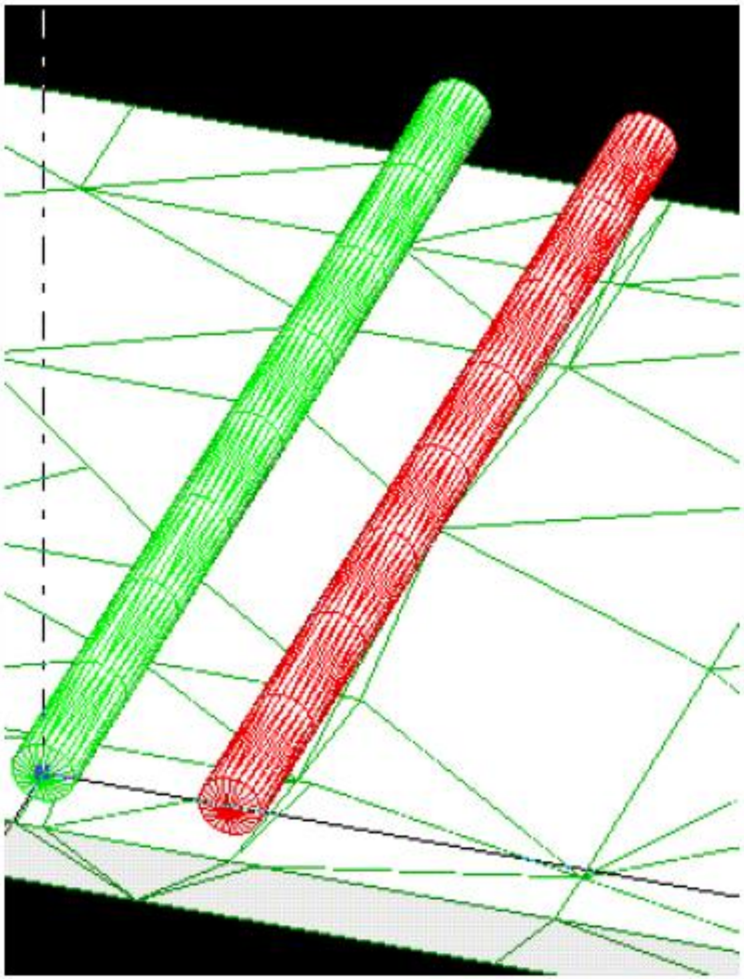
Difference between the n and n-1 iteration

M: calculate the R, L and optimizes the large scale structure of the mesh

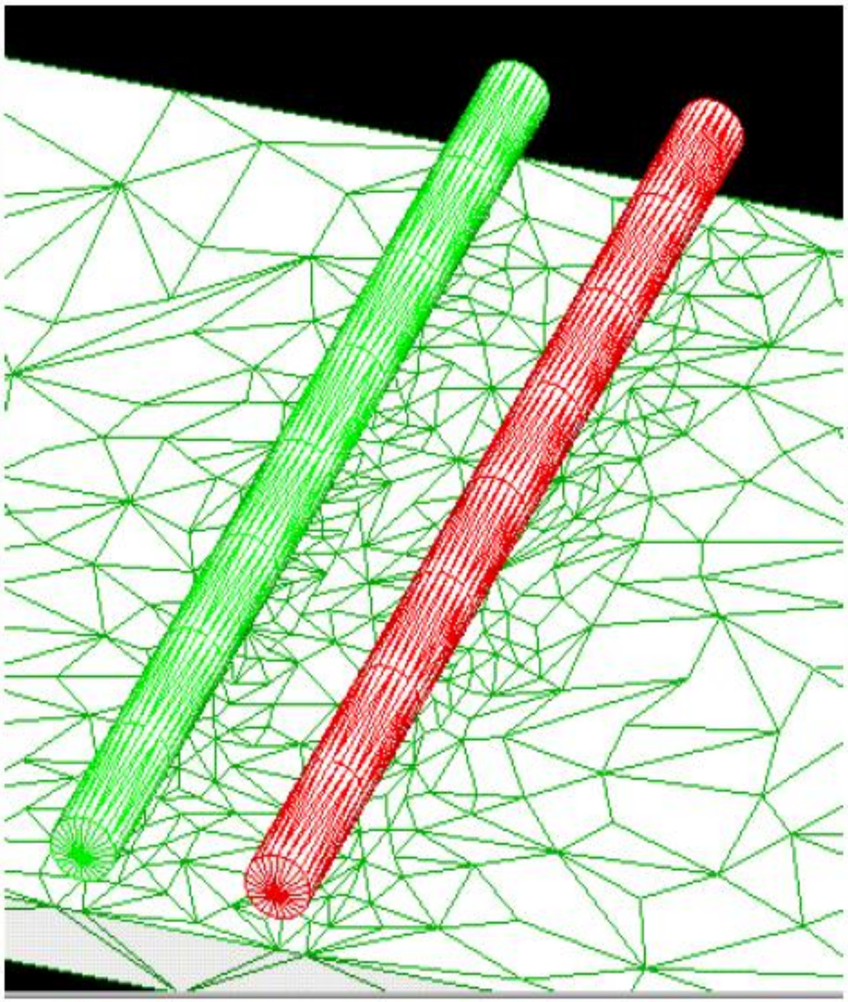


Mesh of DC and AC solution

DC

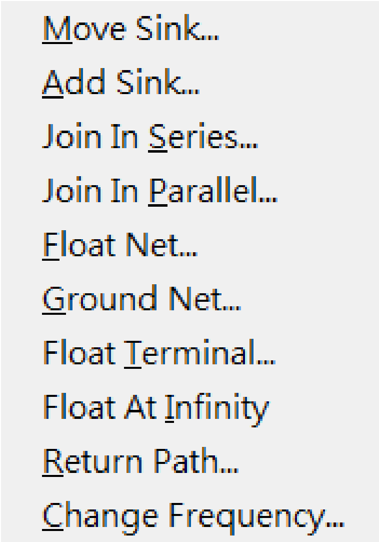


AC



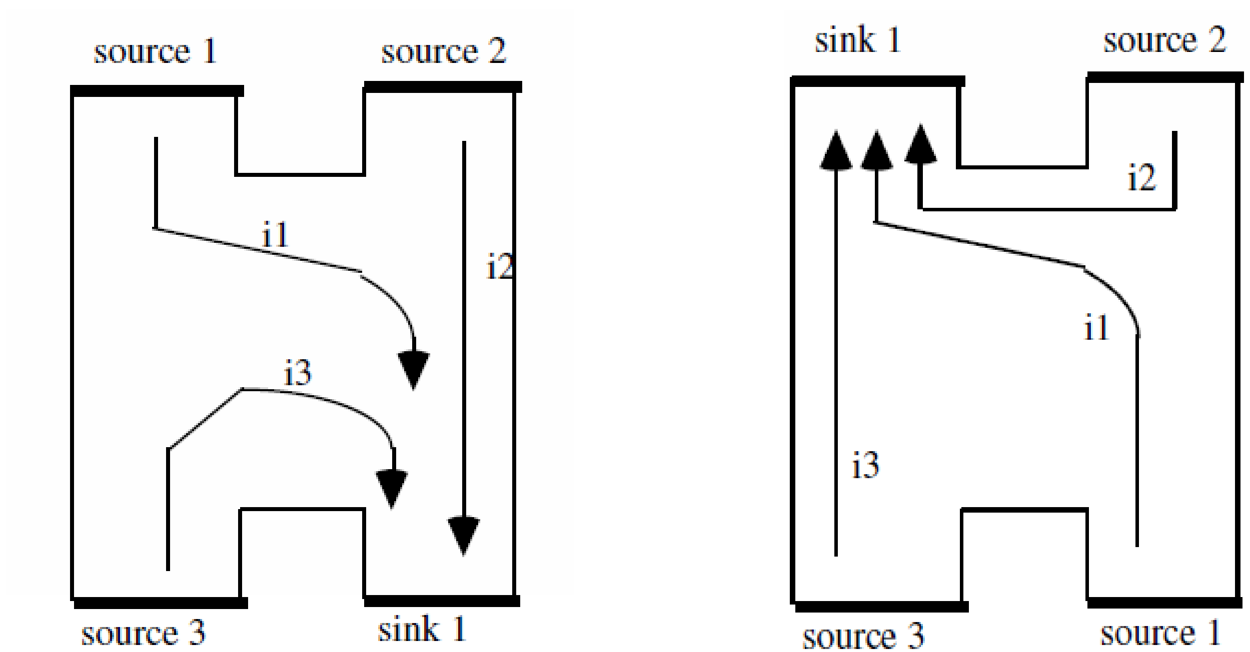
Reduced matrix operation

- 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

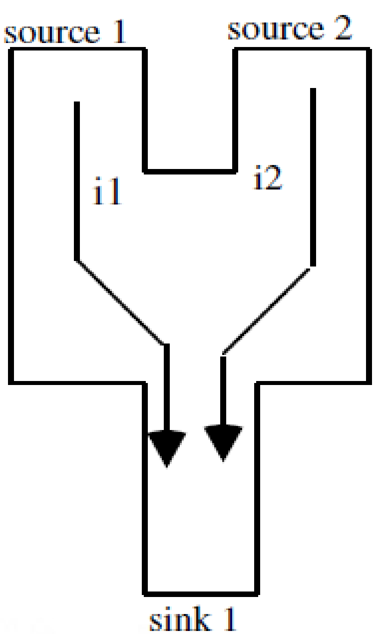
- Let you switch the placement of sink terminals in a conductor without having to change the terminal assignment and generate a new solution.

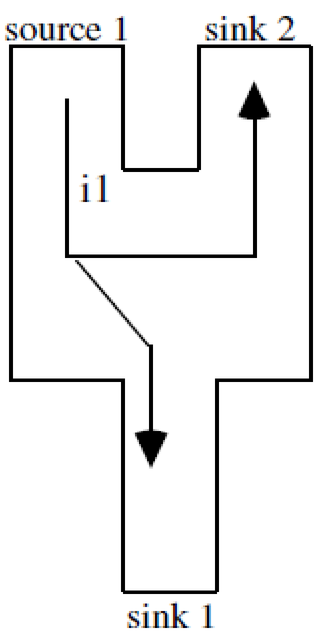


$$i_{out} = i_1 + i_2 + i_3$$

Add sink

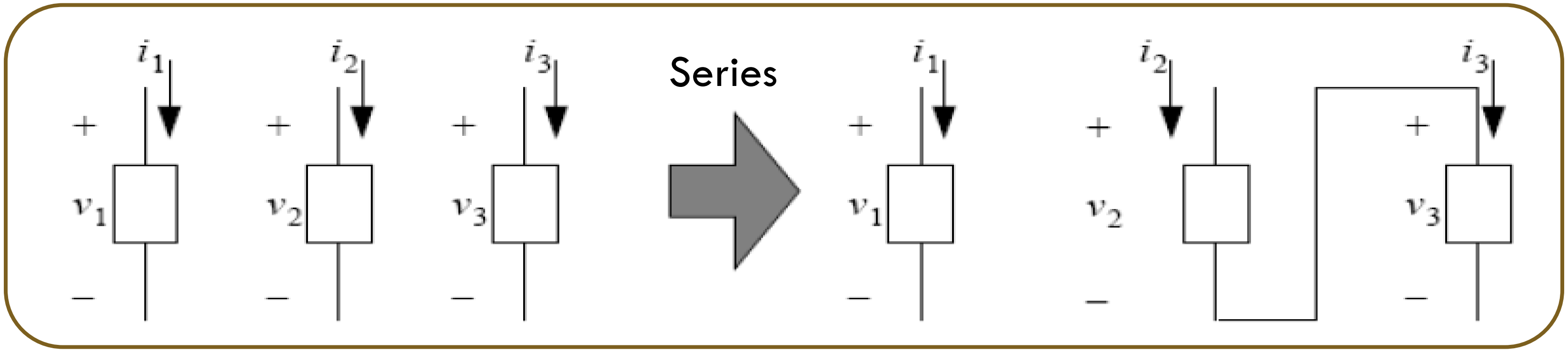
- Allow user to add current sinks to a model without having to change the setup and generate a new solution.
- Allows user to simulate the presence of multiple current sinks in a conductor. While actually solving the model, only a single sink is allowed for conduction simplicity.

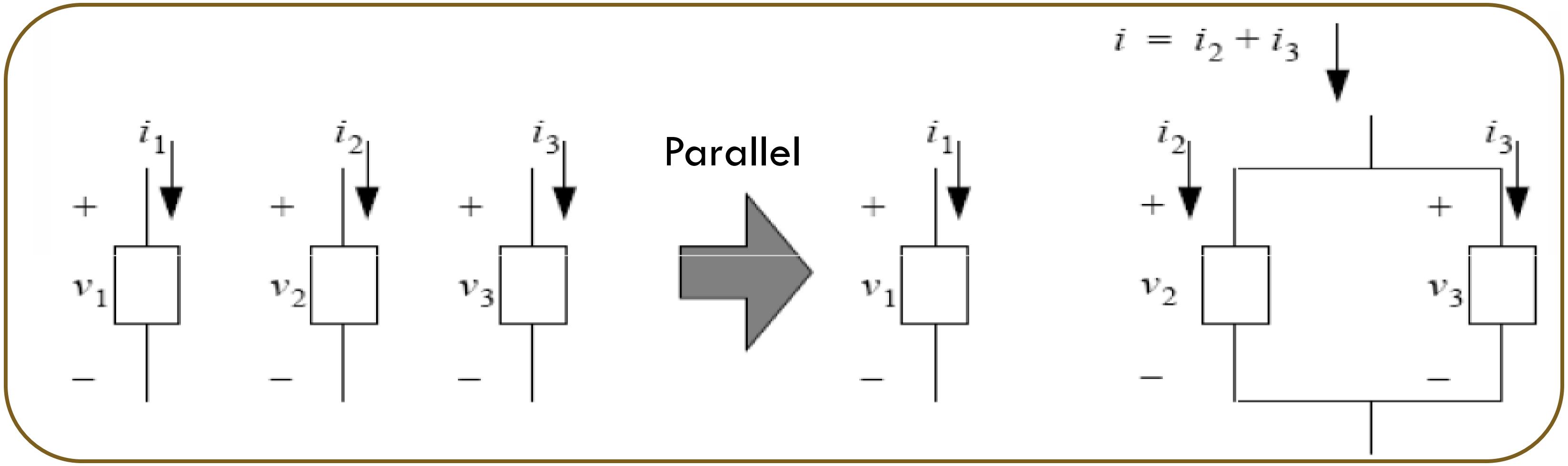




Join in series and parallel

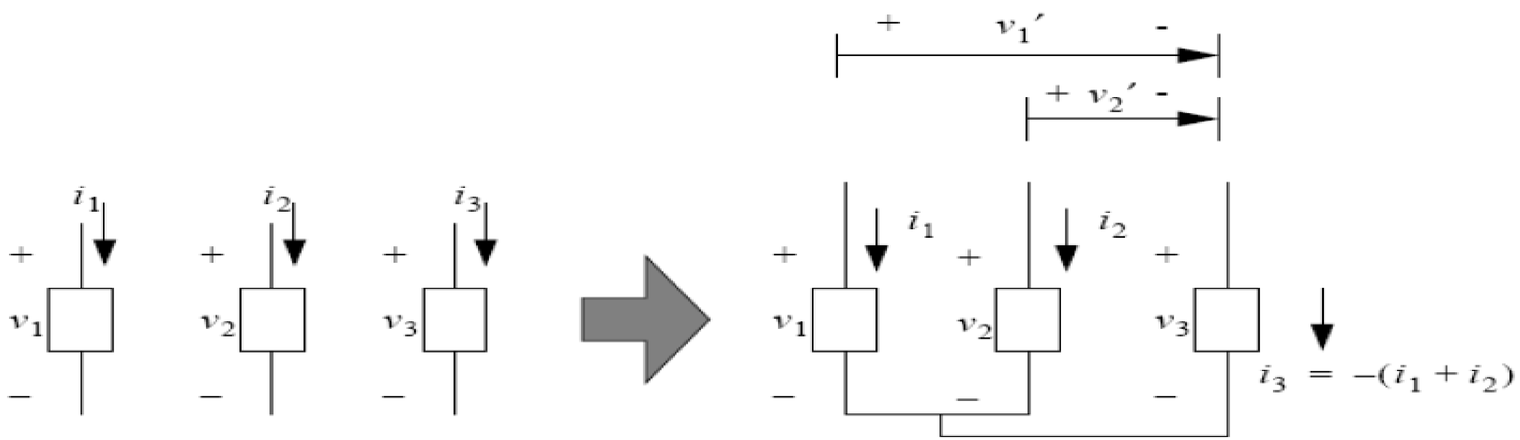
- This feature allows you to connect two or more conductors in series and parallel.





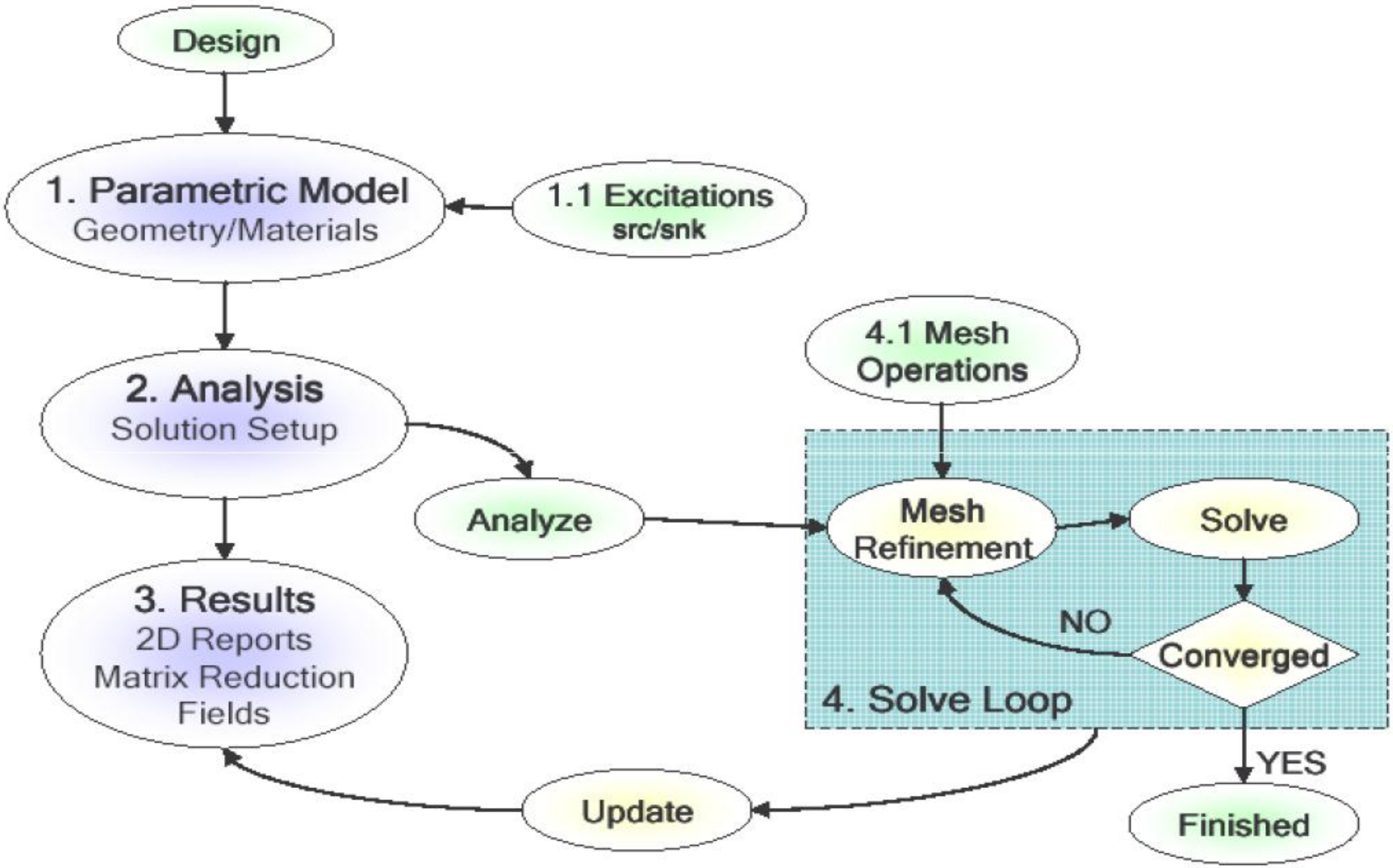
Ground net and Return path

- 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



Reference

- A. E. Ruehli, "Inductance calculations in a complex integrated circuit environment," *IBM J. Res. Develop., vol. 16, pp. 470-481, Sept. 1972.*
- A. E. Ruehli and P. A. Brennan, "Capacitance models for integrated circuit metallization wires," *IEEE J. Solid-State Cir., vol. SC-10, pp.*530-536, Dec. 1975.