

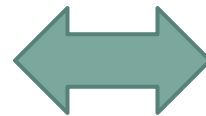
# ANSOFT Q3D TRAINING



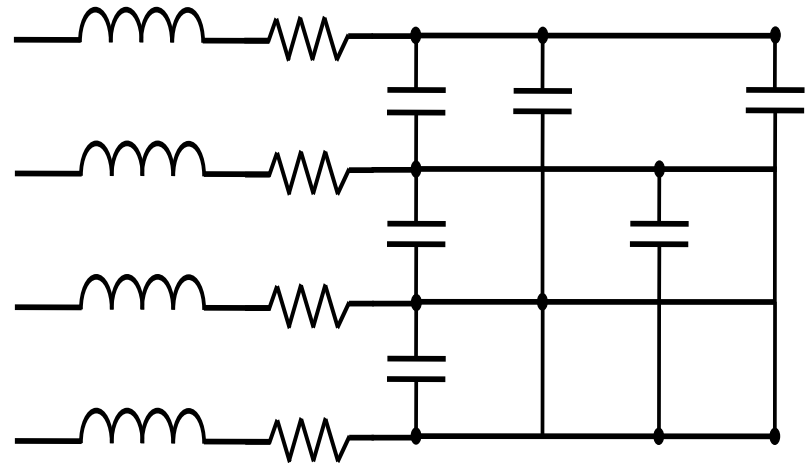
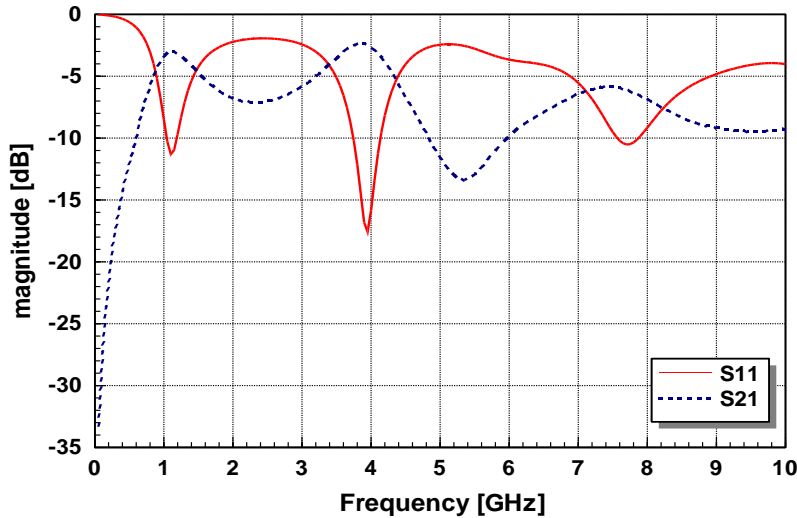
# Introduction



**HFSS**  
3D EM Analysis  
S-parameter

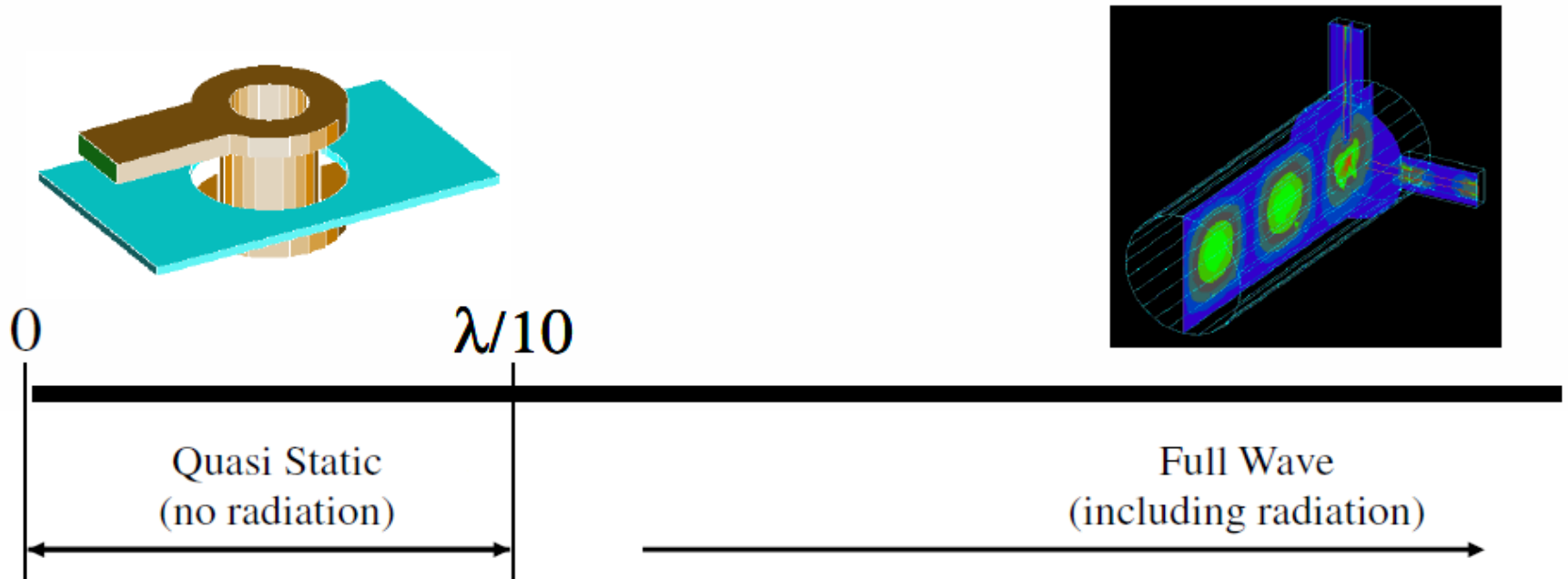


**Q3D**  
R/L/C/G Extraction  
Model



# Quasi-static or full-wave techniques

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

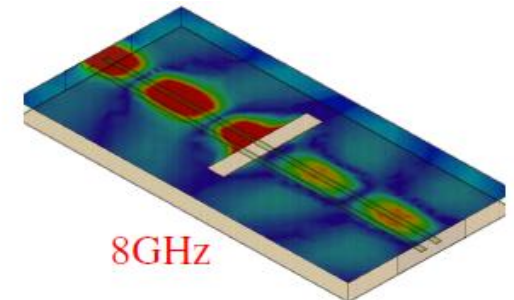
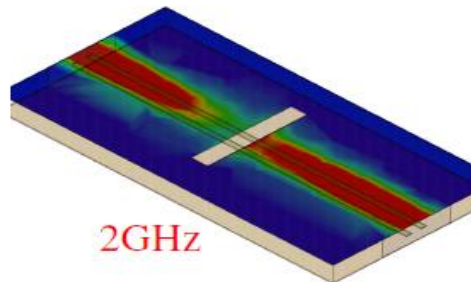
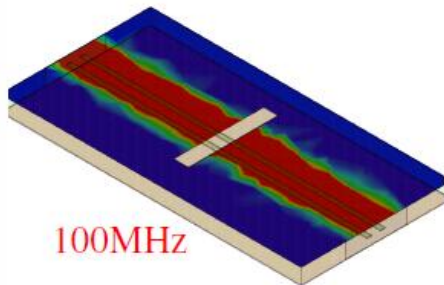
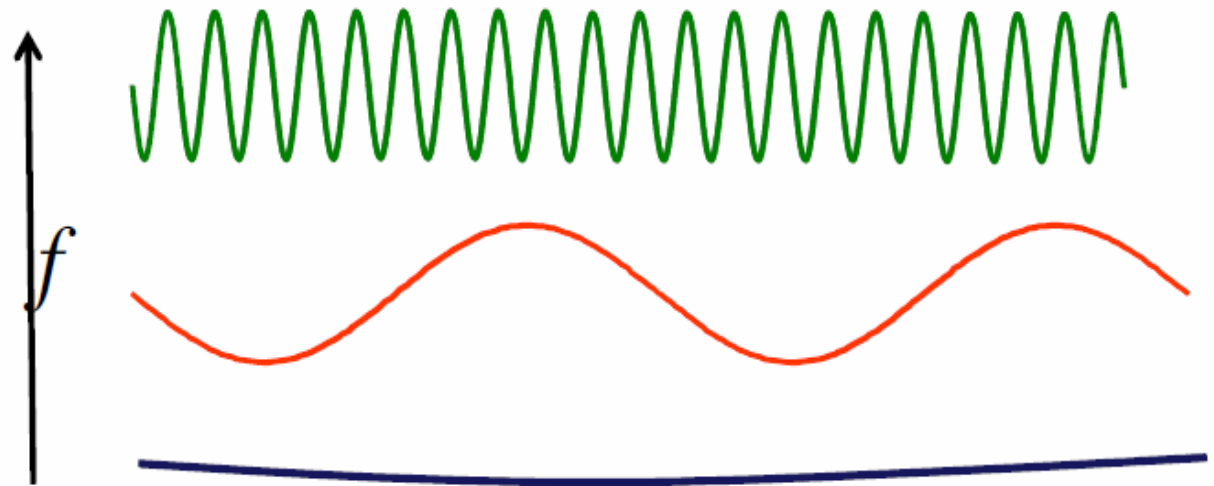


- Size  $< \lambda/10$ , use quasi-static solvers. Output circuit model in RLGC.
- Size  $> \lambda/10$ , and/or radiation important, use full-wave solvers. Output S, Y, and Z parameters and fields.

# Wavelength issues

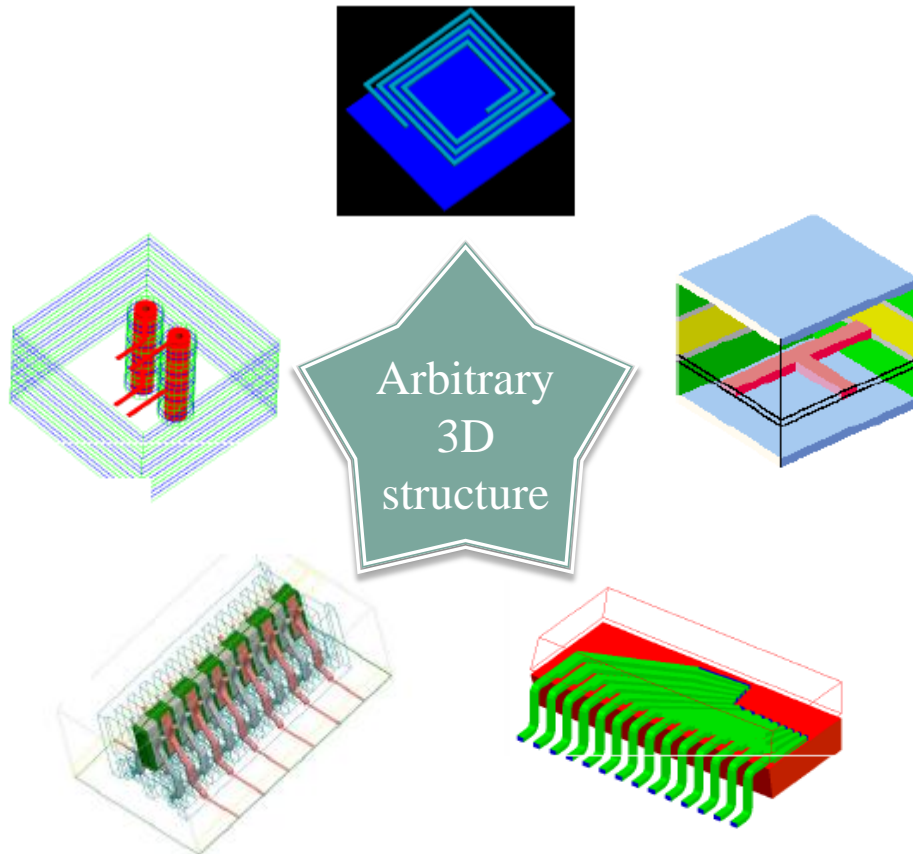
- low frequencies (lump model) :  $\lambda/10$  wavelengths  $\gg$  wire length

$$v_p = \lambda \times f$$

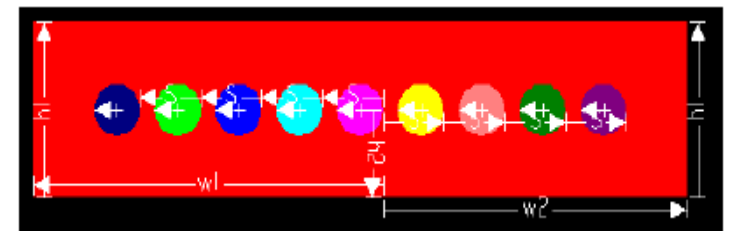
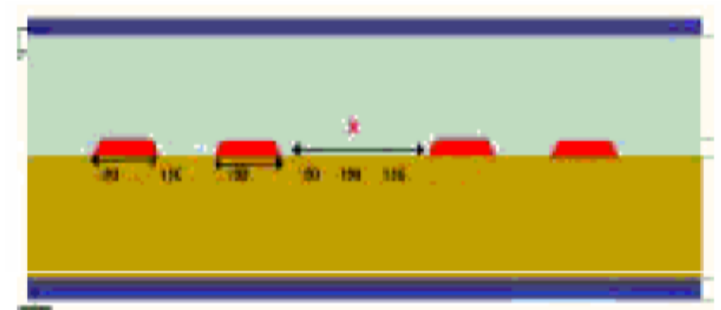


# Q3D Extractor

## 1. 3D Fast Quasi-static EM solver



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

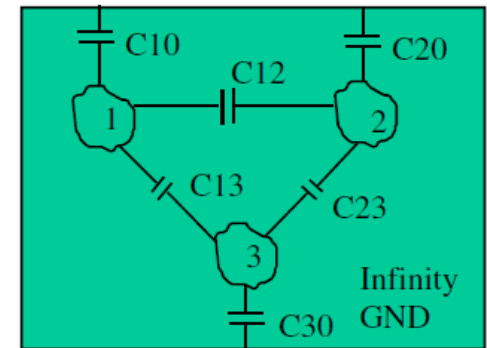


# Capacitance matrix

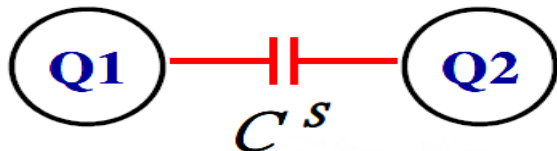
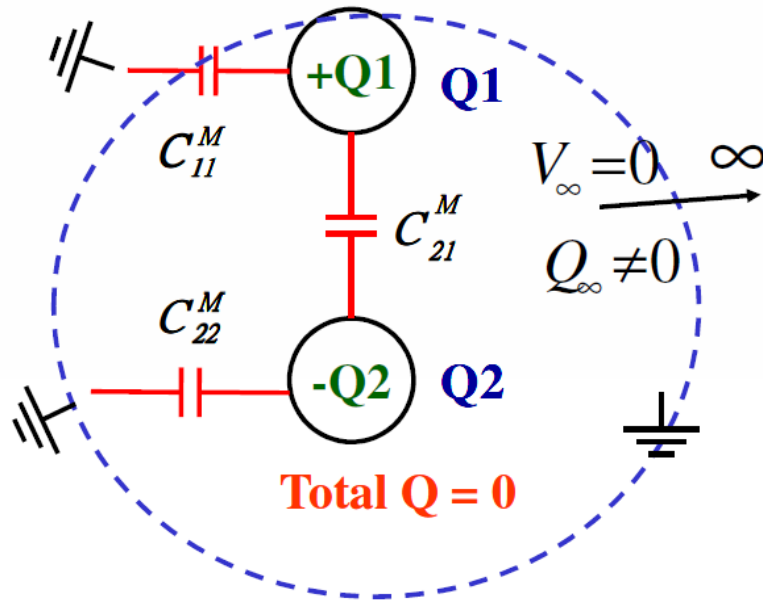
- The equation relating the total charge on a capacitor with the potential difference relative to a ground at zero volts is :  $Q=CV$
- In a three-conductor system, matrix notation is used:

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

- 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:

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

circuit solution:

$$Q_1 = C_{11}^k V_1 + C_{12}^k (V_1 - V_2)$$

$$Q_2 = C_{21}^k (V_2 - V_1) + C_{22}^k V_2$$

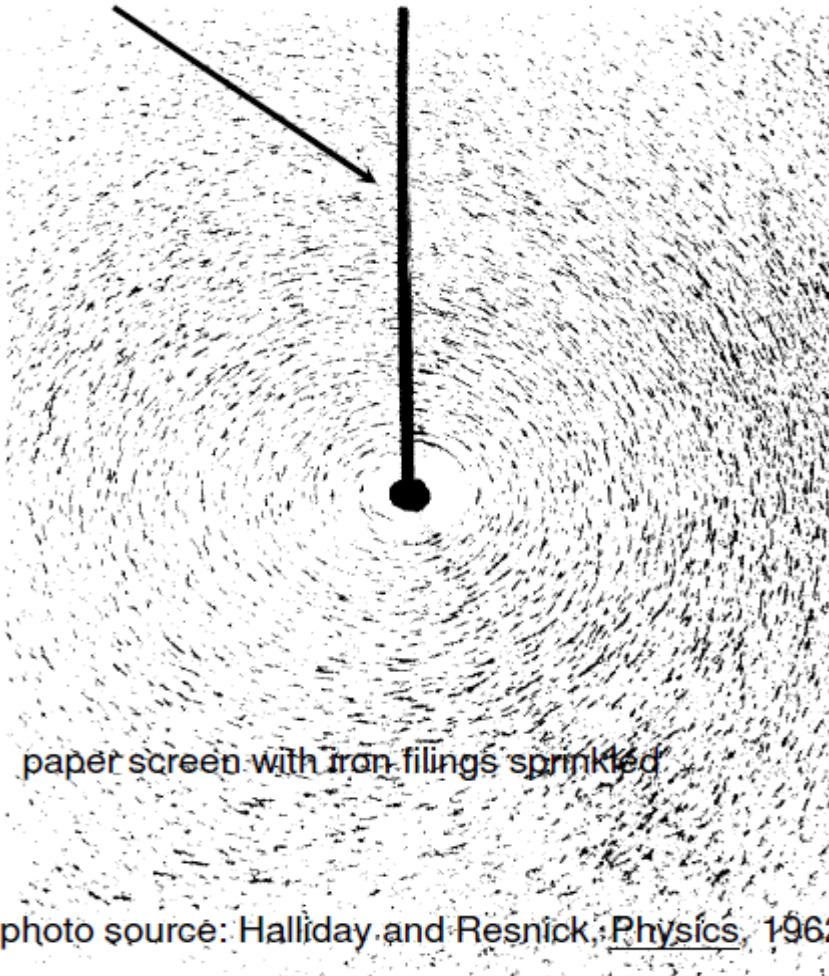
➔

$$C_{11}^S = C_{11}^k + C_{12}^k$$

$$C_{12}^S = -C_{12}^k$$

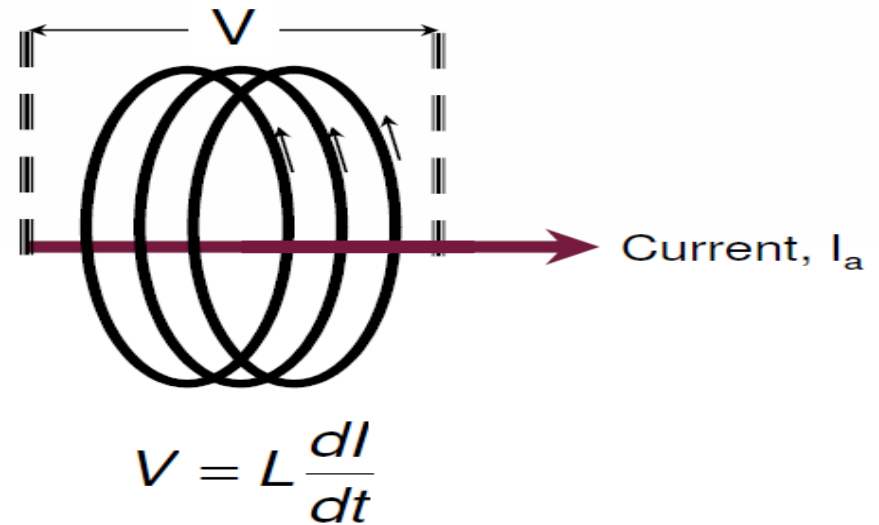
# Self-inductance

wire carrying a current



paper screen with iron filings sprinkled

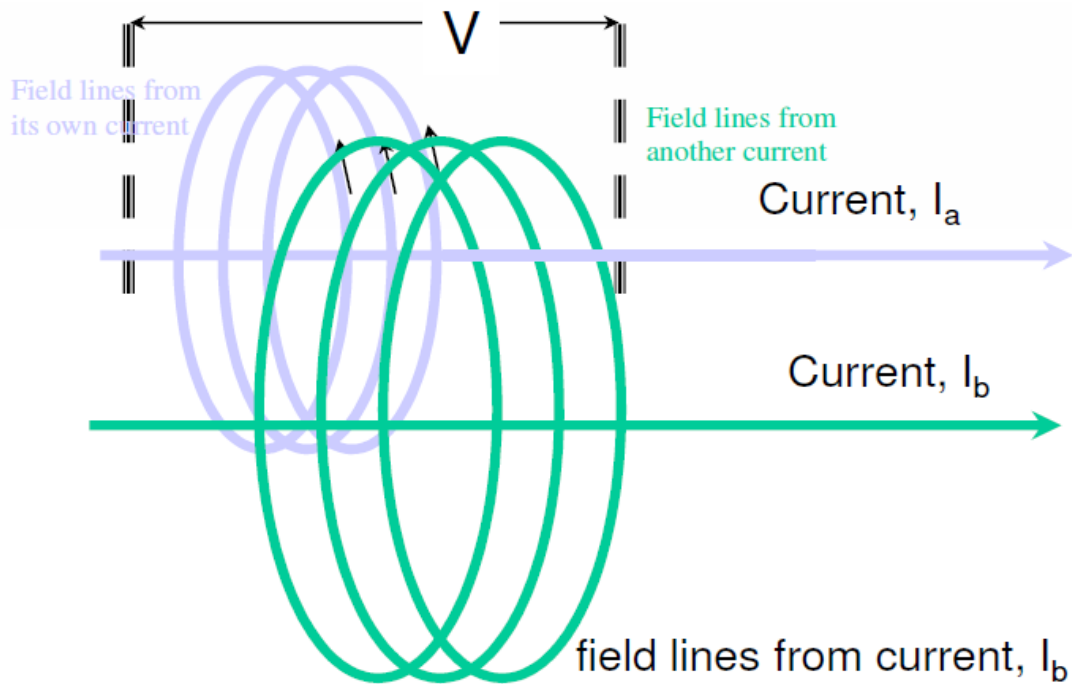
photo source: Halliday and Resnick, Physics, 1962





# Mutual-inductance

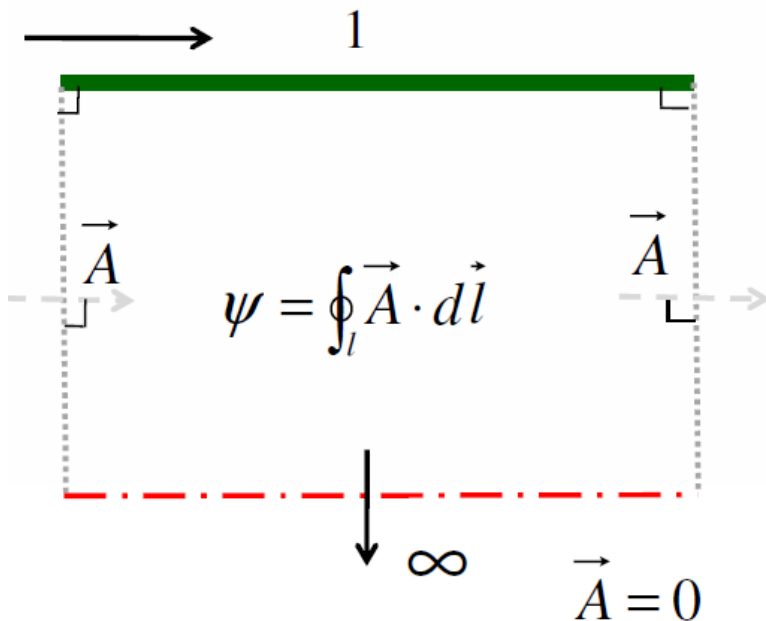
- A voltage is induced across a conductor when the number of field lines around it changes.



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

# 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.



# Partial inductance matrix

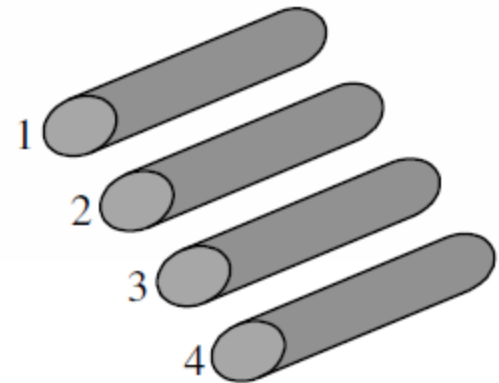
- Defined for any collection of conductors

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

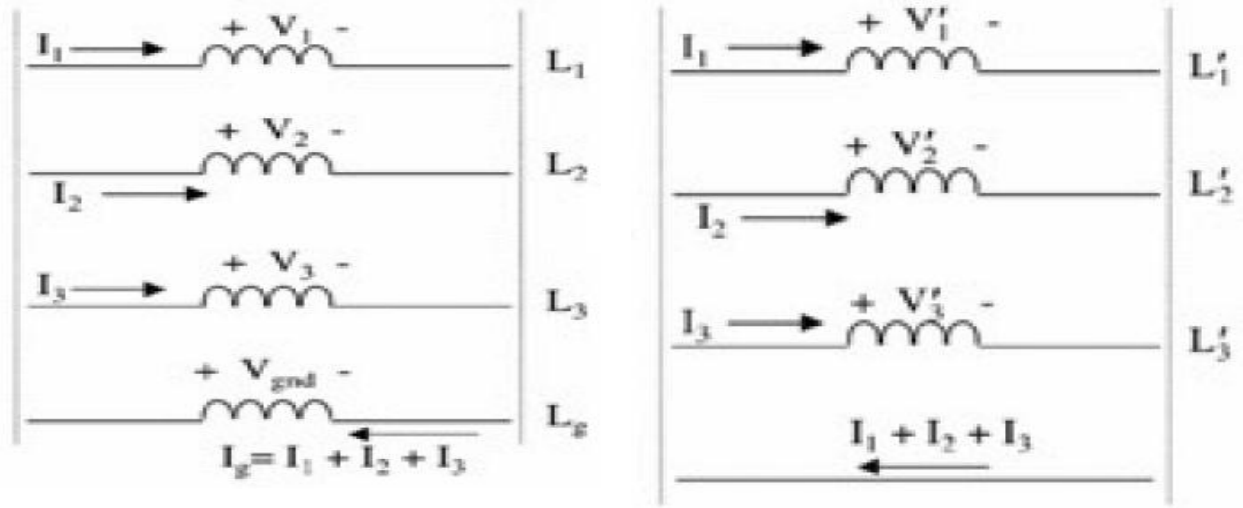
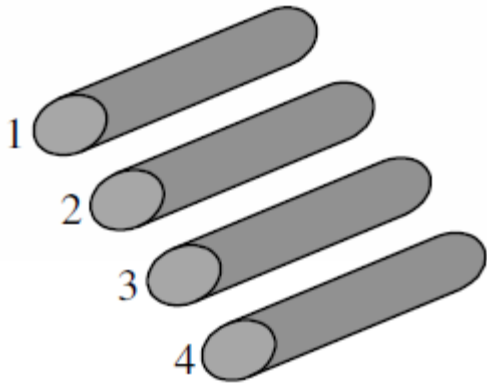
$$V_1 = L_{11} \frac{dI_1}{dt} + L_{12} \frac{dI_2}{dt} + L_{13} \frac{dI_3}{dt} + L_{14} \frac{dI_4}{dt}$$

↑  
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

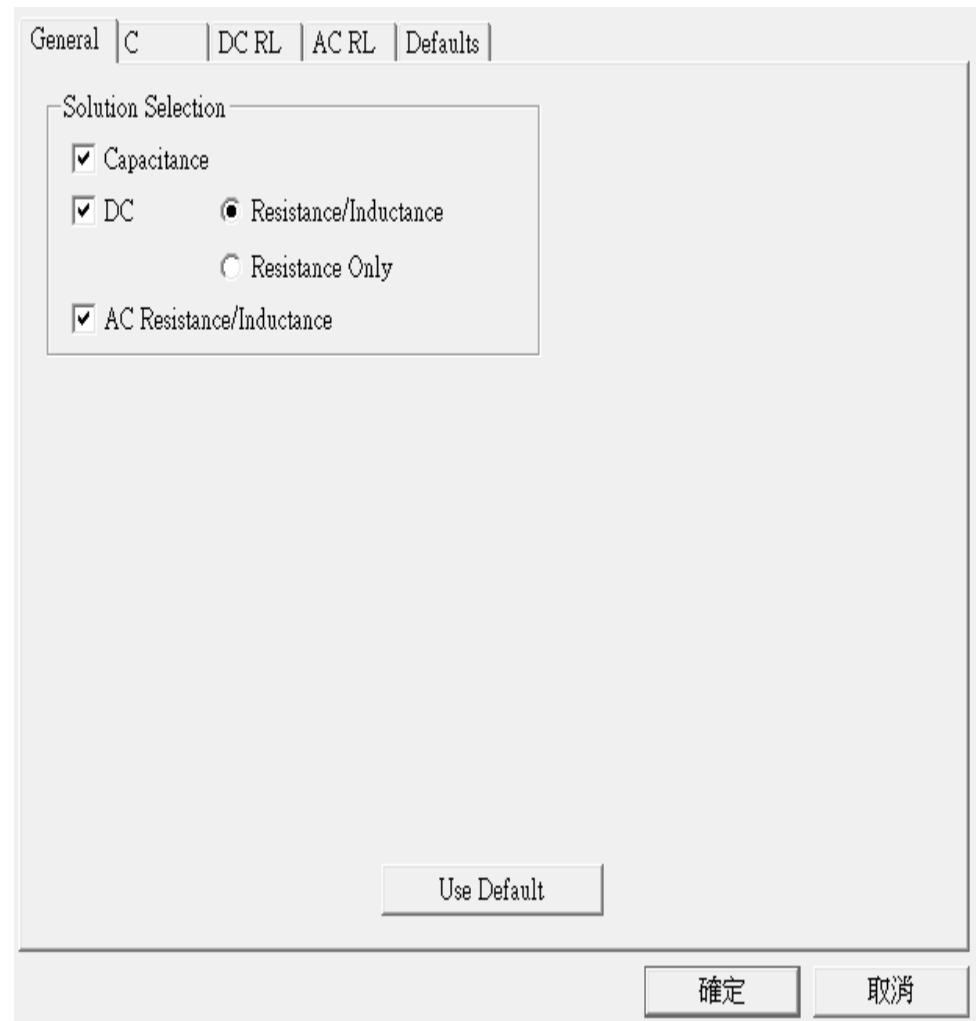
- The individual elements of the inductance matrix are computed in the same way as the elements of the capacitance matrix.
- For a three-conductor system with a well-defined ground return path, the relationship between the magnetic flux in each loop and the current loop  $I$  in each is given by:

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

- 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

The image shows a software dialog box for 'Solve setup' with several tabs: 'General', 'C', 'DC RL', 'AC RL', and 'Defaults'. The 'General' tab is active. At the top, 'Solver Residual' is set to '1e-005', 'Soln. Frequency' is '500', and the unit is 'MHz'. Below this are two sections: 'Conduction Adaptive Solution' and 'Multipole Adaptive Solutions'. Each section has three input fields: 'Maximum Number of Passes' (40), 'Percent Error' (0.1 %), and 'Percent Refinement Per Pass' (30 %). Three yellow arrows point from text boxes on the left to these fields: the top arrow points to the 'Maximum Number of Passes' field, the middle arrow points to the 'Percent Error' field, and the bottom arrow points to the 'Percent Refinement Per Pass' field. At the bottom of the dialog is a 'Use Defaults' button, and at the very bottom are two buttons labeled '確定' (OK) and '取消' (Cancel).

Section	Maximum Number of Passes	Percent Error	Percent Refinement Per Pass
Conduction Adaptive Solution	40	0.1 %	30 %
Multipole Adaptive Solutions	40	0.1 %	30 %

# 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

Design Variation: length='5.6mm'

Simulation: Setup1 AC RL

Matrix Convergence Profile

Pass	Type	# Triangle	DeltaR	DeltaL
1	C	82	N/A	N/A
2	M	93	0	N/A
3	M	108	3.965...	6.255
4	M	135	0	2.1786
5	M	155	5.948...	9.7471
6	M	190	1.982...	13.841
7	M	240	3.965...	7.5734
8	M	305	3.965...	3.2155
9	M	391	1.982...	3.1687
10	M	501	0	1.819
11	M	651	3.965...	1.6321
12	M	864	3.965...	2.4348

Number of Passes (R, L)  
Completed (1, 33)  
Maximum (40, 40)  
Minimum N/A

Delta (R, L) %  
Target (0.1, 0.1)  
Current (9.9138e-010, 0.53005)

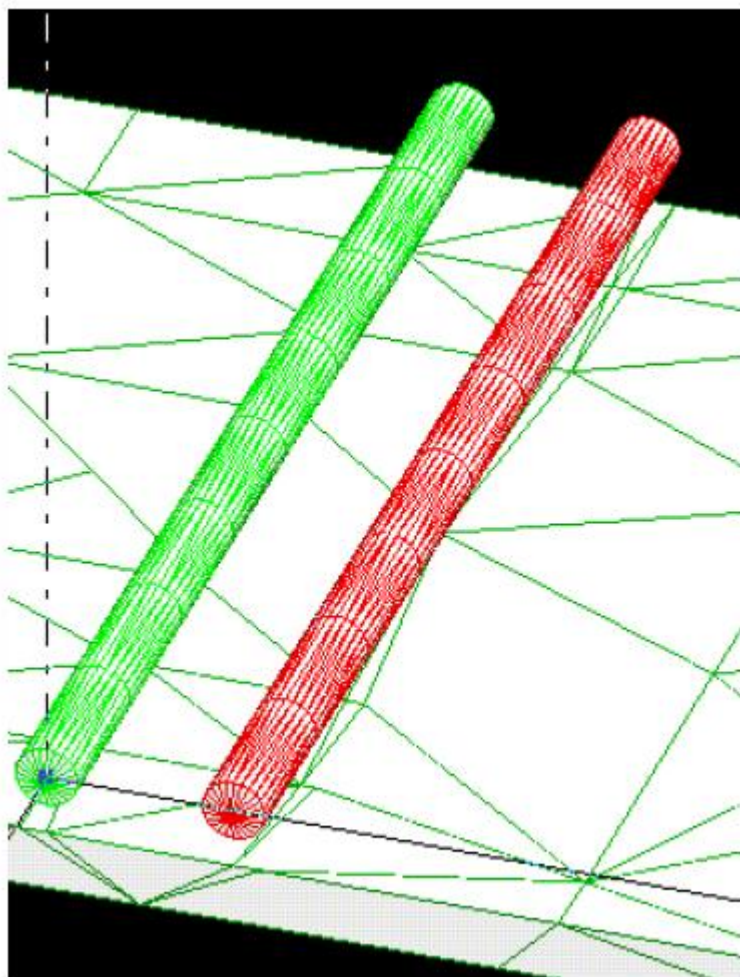
View:  Table  Plot

Close

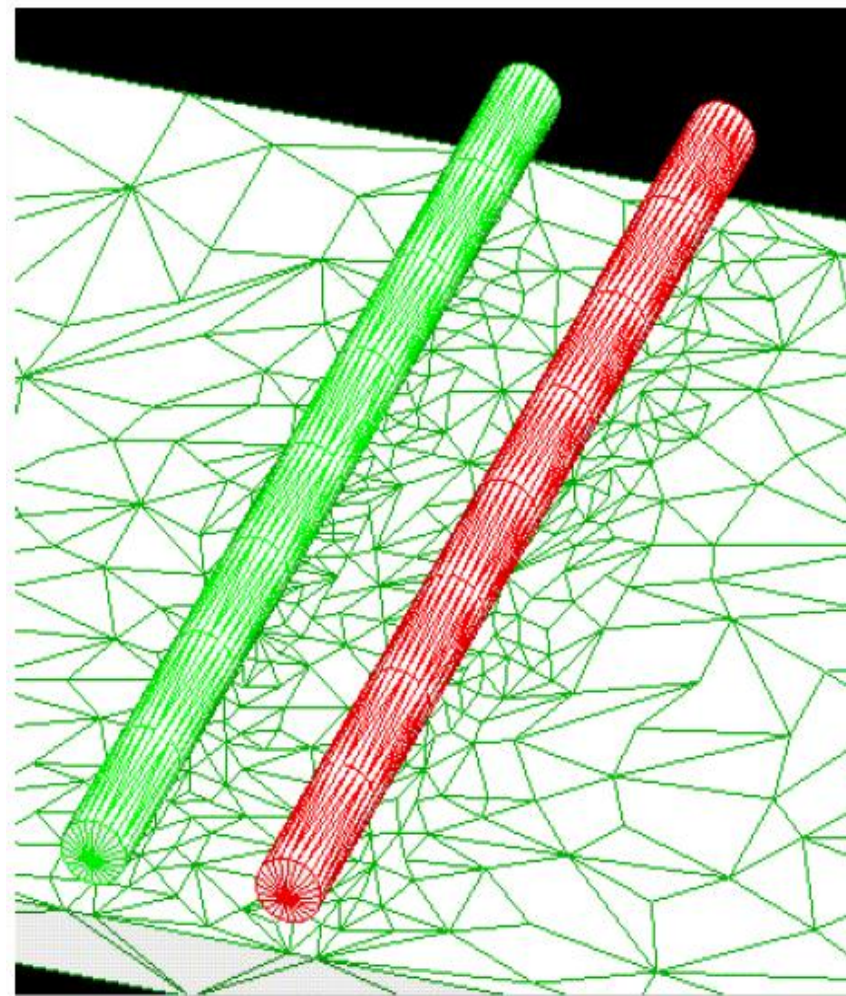


# Mesh of DC and AC solution

DC



AC



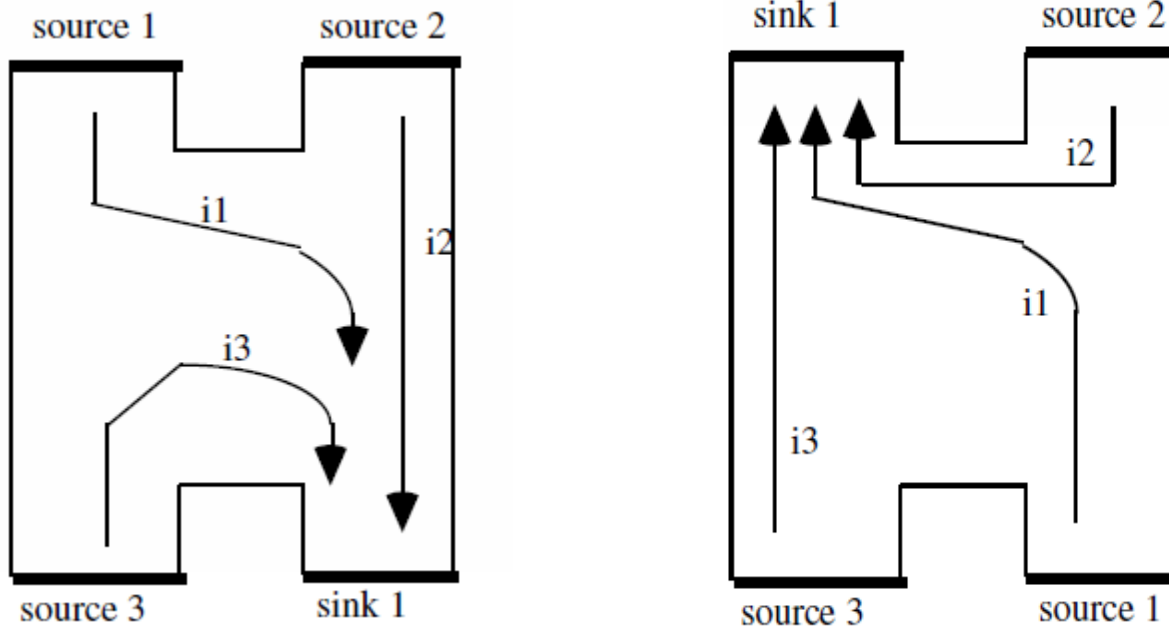
# Reduced matrix operation

- 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...  
Add Sink...  
Join In Series...  
Join In Parallel...  
Float Net...  
Ground Net...  
Float Terminal...  
Float At Infinity  
Return Path...  
Change Frequency...

# Move sink

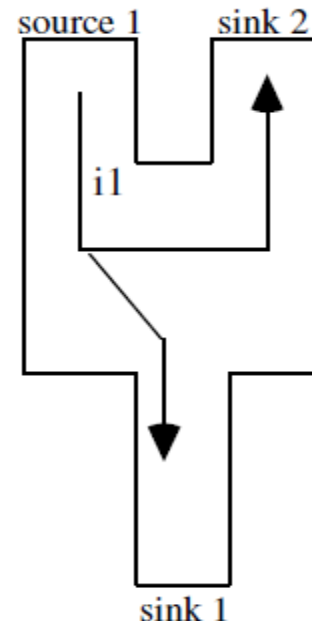
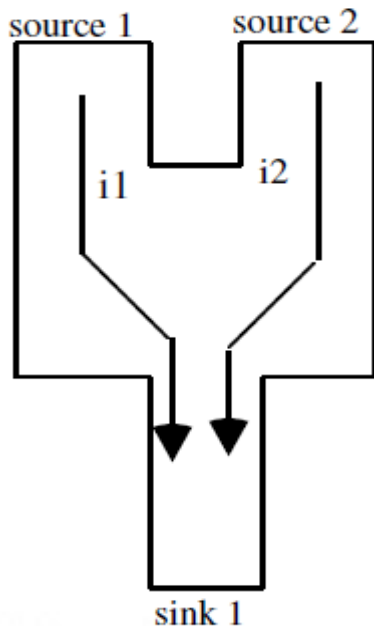
- Let you switch the placement of sink terminals in a conductor without having to change the terminal assignment and generate a new solution.



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

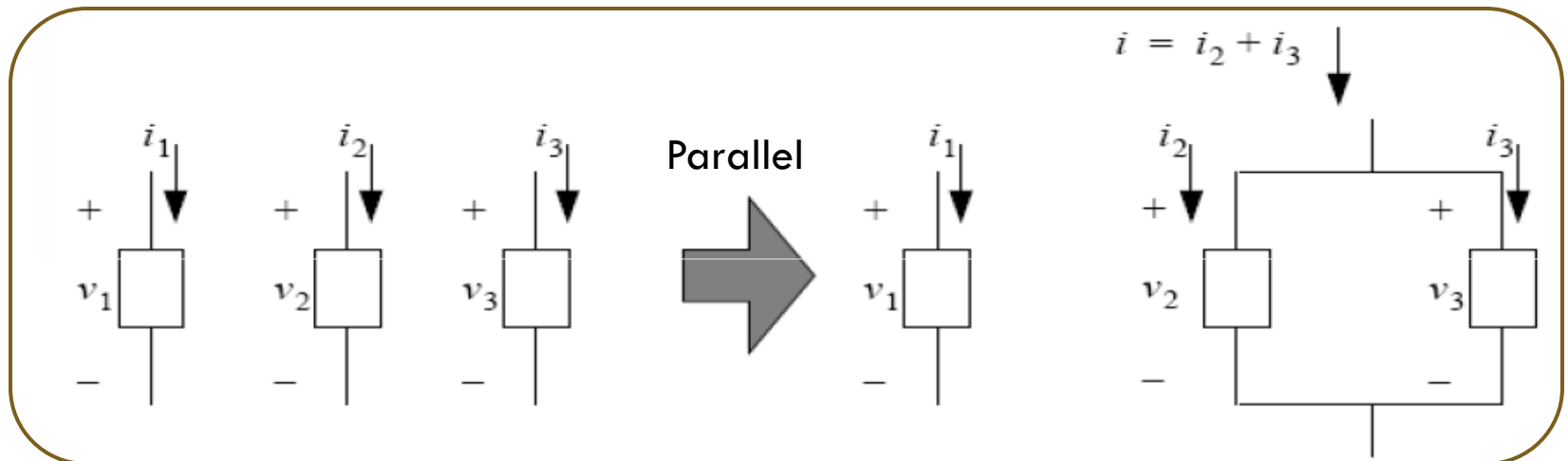
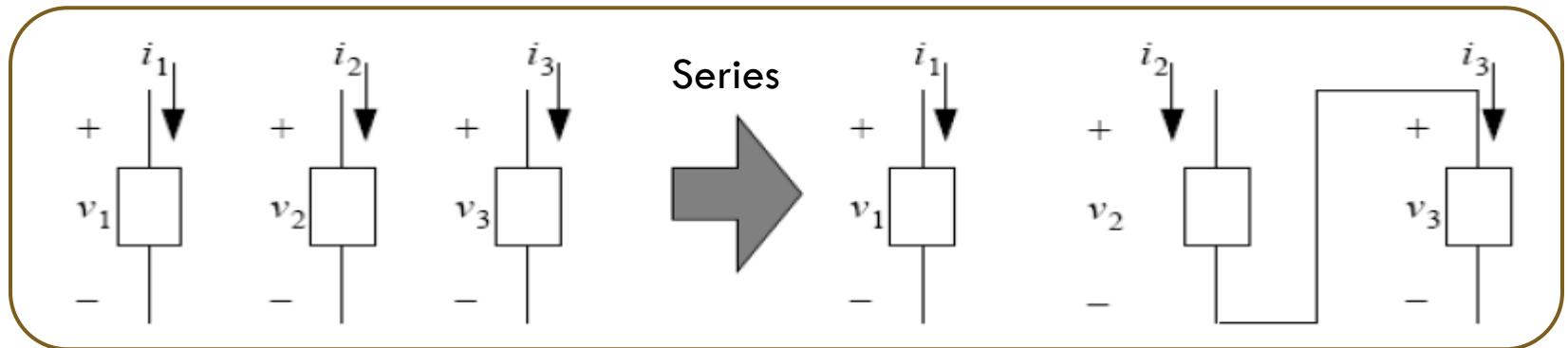
# Add sink

- 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.



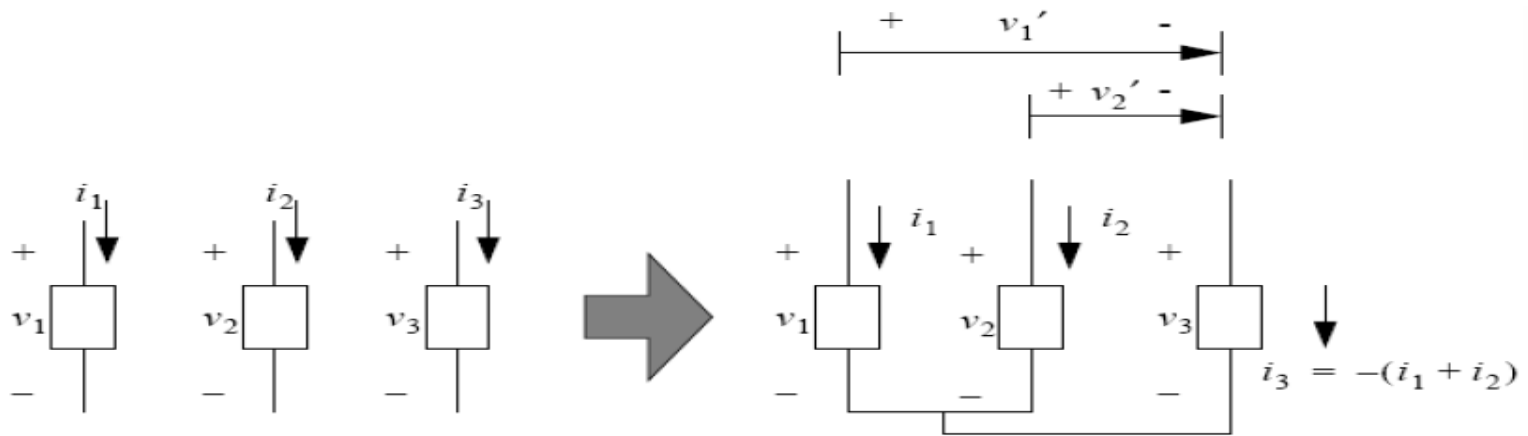
# Join in series and parallel

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



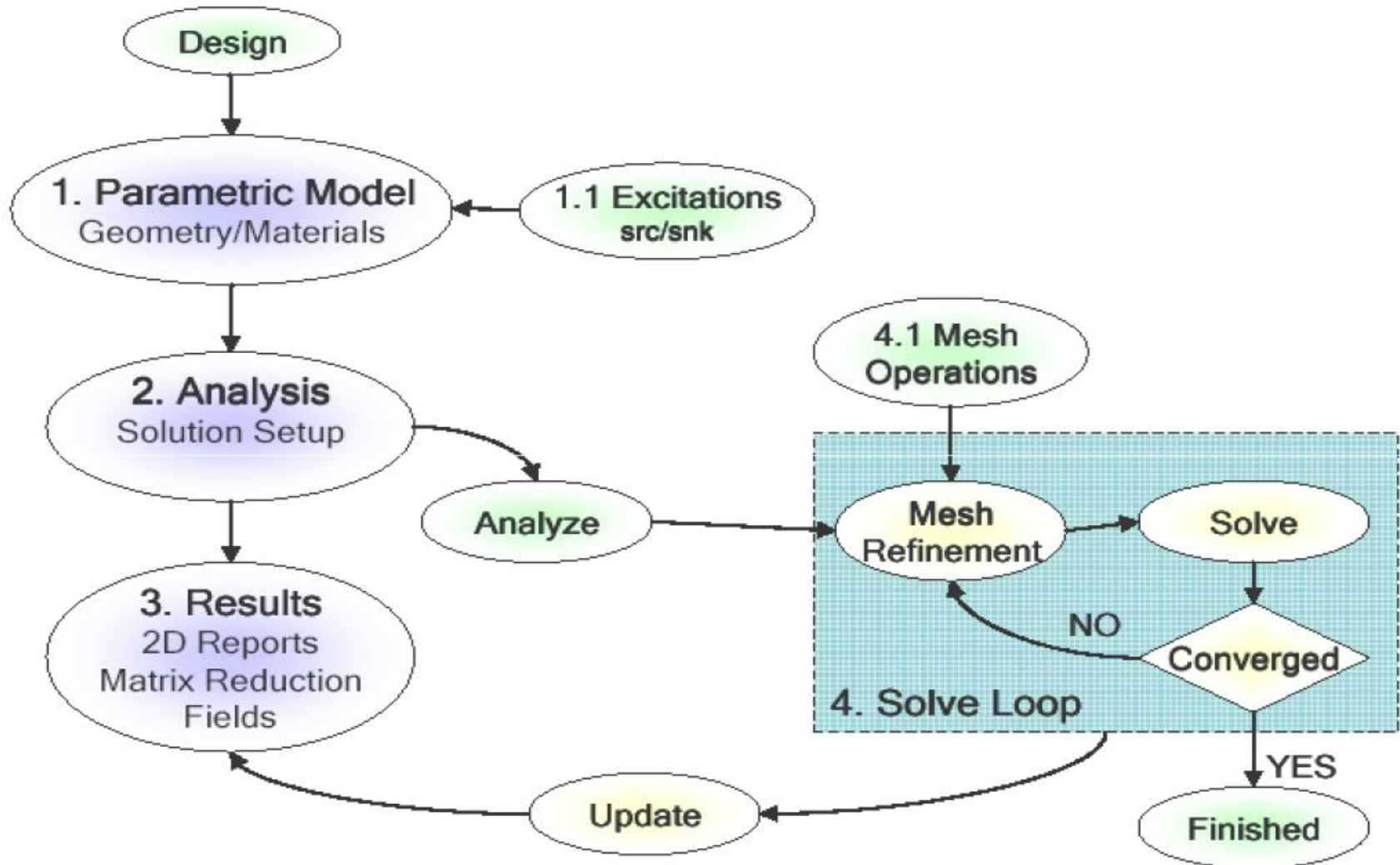
# Ground net and Return path

- 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.