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October 22, 2003

What's All This Planar EM simulation Stuff Anyhow ?

AGENDA

- **What and Why – Momentum ?**

  How does momentum fit in the

  Grand scheme of Agilent ADS?
- **Under lying technologies:**

  Method of Moments

  Mesh reduction   Quasi static approximation

  Star-loop basis functions

  Adaptive frequency sampling

  MAPS
- **What is the design flow?**

  The starting point

  The set up

  Mode

  Substrate stack

  Layer definition and mapping

  Mesh set up

  Simulation set up
- **Unique features**

  Momentum RF

  Schematic to lay out flow

  Co simulation

  Co optimization

  Statistical design of physical circuits

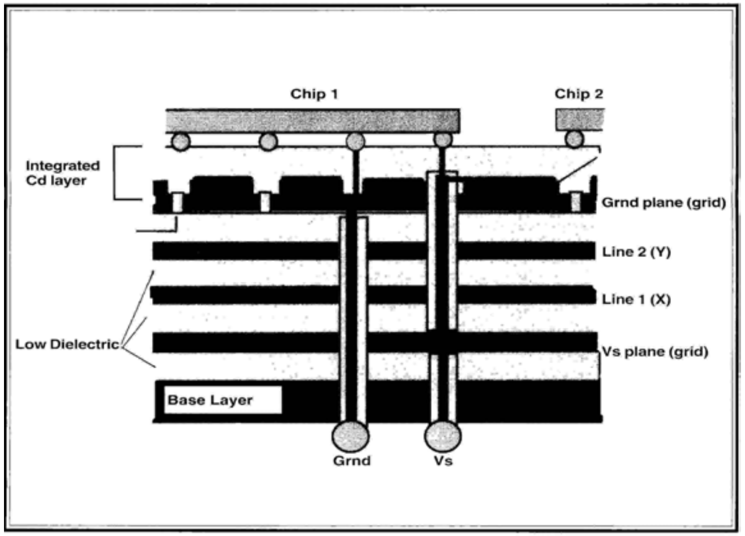
  Visualization

  Spice model generator
- **Bench marks and Examples**

What is meant by Planar EM simulation ?

- Substrate - multiple dielectrics
- Metals - traces on different layers forming component and/or thin film interconnect
- Vias - connecting different layers
- Method of Moments technique
- Sometimes referred to as 2.5D

- It does NOT include:
  - Arbitrary 3D structures
  - Horn Antennas



Why are Planar EM Simulators used ?

- No simple analytical model exists
- Coupling between conductors or layers is significant
- Arbitrary planar geometry
- Narrow frequency response not captured by analytical models
- Radiation patterns of planar antennas
- CPW transmission lines

- When full 3D analysis would take too long

Agilent EEsof RF AM/S (Analog Mixed Signal) Simulation Technologies

Linear

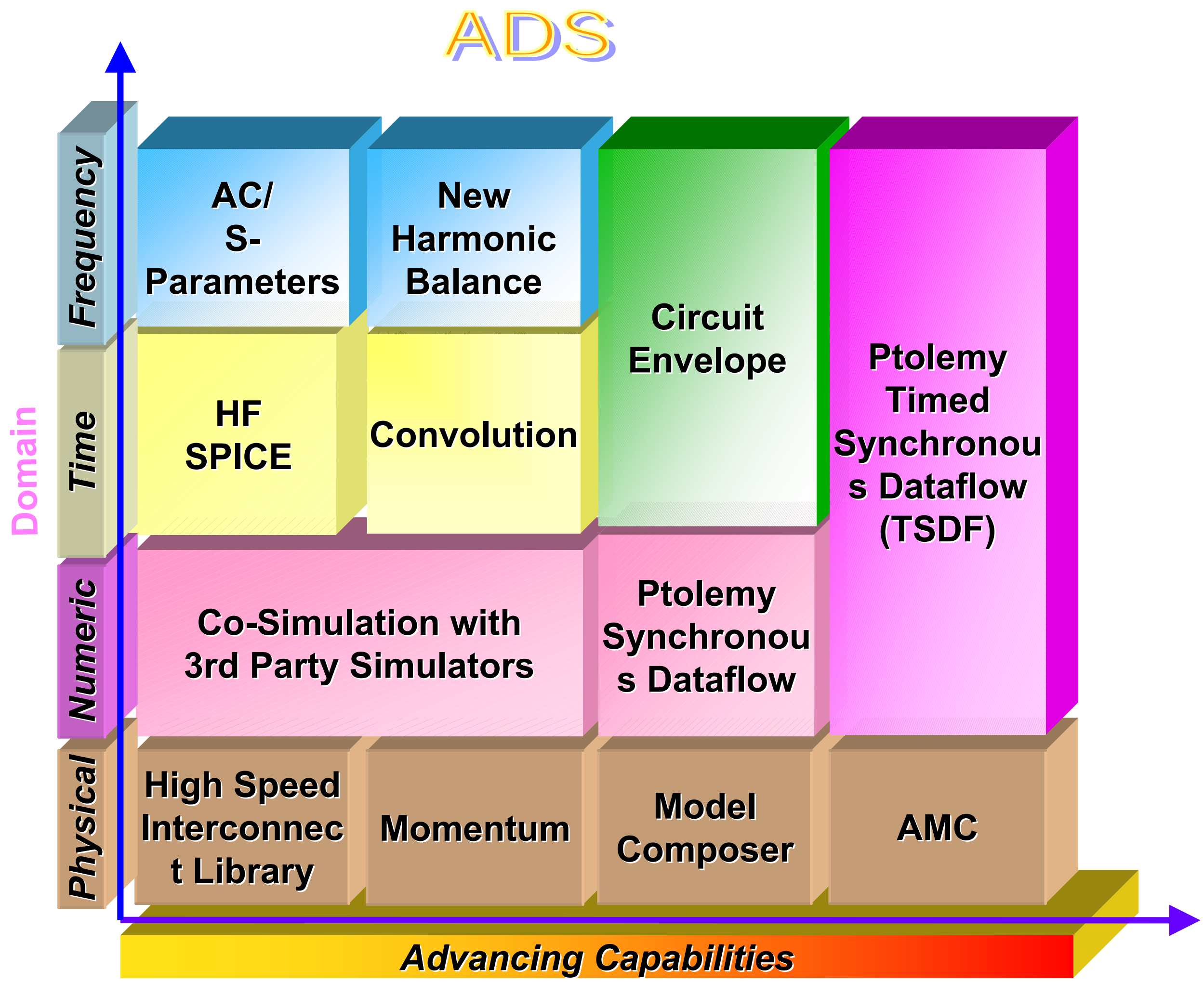
Harmonic Balance
Krylov Solver
Transient Assisted HB

Circuit Envelope

Convolution
High Frequency SPICE
RF System Simulator

Ptolemy
Ptolemy Fixed Point
Digital Filter
E-Syn

Planar EM



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Method of Moments

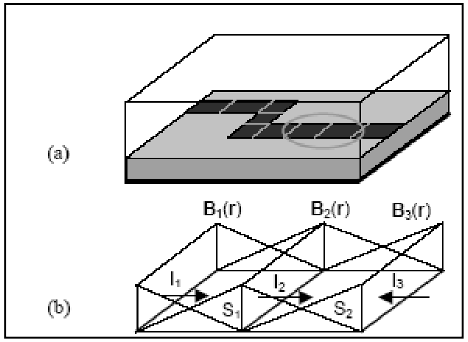
Other names related to this topic or method (some very old and others relatively recent) are "Variational Method", "Rayleight-Ritz Method", "Weighted Residual Method", "Method of projections", "Petrov-Galerkin Method" and "Boundary Element Method". They all share a common theme or approach and basically accomplish the same goal; viz., *to turn differential and integral equations with continuous variables into matrix equations that can be solved on the computer*. This is the essence of the formal procedure that follows.

Fourier analysis is another example of the many forms of discretization. Given a function f(x) over the period $0 \le x \le a$, we can define a harmonic series of the form

$$f(x) = \sum_{n=0}^{\infty} \left(A_n \cos\left(\frac{2n\pi x}{a}\right) + B_n \sin\left(\frac{2n\pi x}{a}\right) \right) \qquad (1.1)$$

where $n = 0,1,2,\ldots \infty$ and the coefficients (A_n, B_n) are respectively the amplitudes of the **"harmonic basis functions"** $[\cos(2n\pi x/a), \sin(2n\pi x/a)]$. The coefficients (A_n, B_n) constitute discretized values that describe the function f(x) and can be used and manipulated as numbers in the computer.

Planar EM Simulation Basics



- The planar structure is decomposed
  - Substrate layer stack of infinite lateral extent
  - Finite metallization patterns
- The metallization patterns are meshed
  - Rectangular, triangular or improved polygonal cells
- Maxwell's equations are translated into integral form
- Surface currents modeled with rooftop basis or Star loop functions
- Boundary conditions imposed by applying Galerkin testing procedure

The mixed potential equation in its general form can be written

$$\iint dS\,\overline{\overline{G}}(r, r') \cdot J(r) = E(r)$$

Resulting MOM interaction matrix equation is of the form

for i=1,...,N $\quad \sum_{j=1}^{N} Z_{i,j} I_j = V_i \quad \text{or} \quad [Z].[I] = [V]$ (1)

with $\quad Z_{i,j} = \iint_S dS\, B_i(r) \cdot \iint_{S'} dS'\, \overline{\overline{G}}(r, r') \cdot B_j(r)$ (2)

and $\quad V_i = \iint_S dS\, B_i(r) \cdot E(r)$ (3)

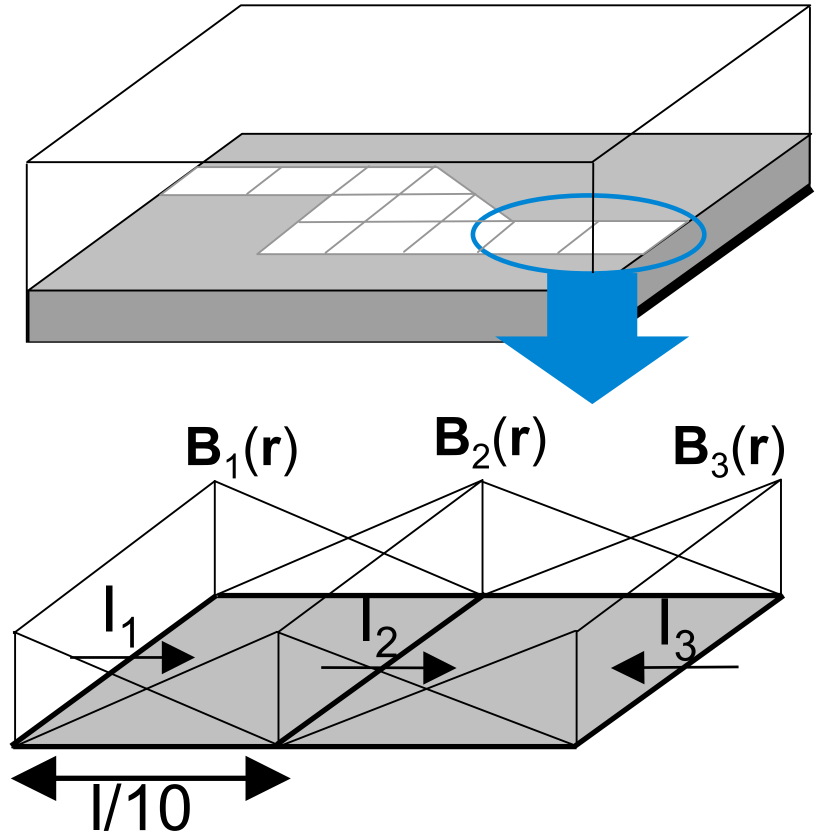
Planar EM Simulation Basics

Physical Design

- Substrate
- Metallization
- Ports

Method of Moments

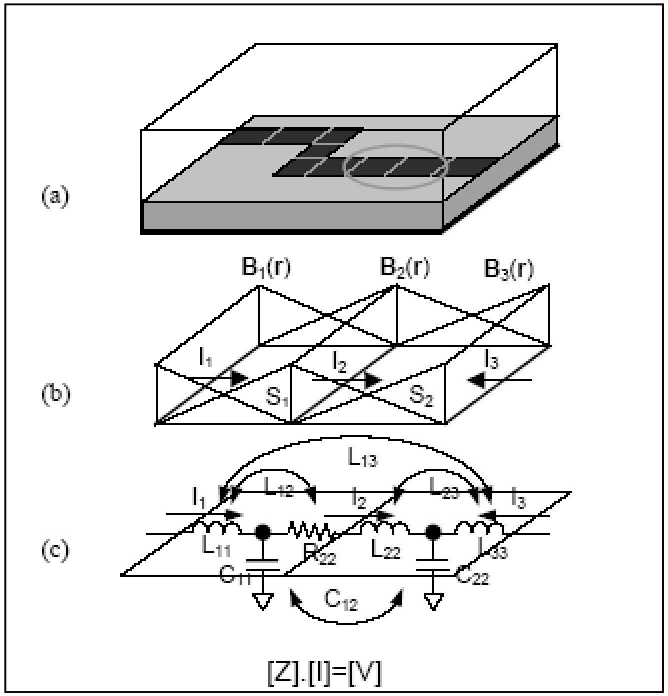
- Meshing
- Rooftop functions



$$\mathbf{J(r)} = I_1\mathbf{B}_1(\mathbf{r}) + I_2\mathbf{B}_2(\mathbf{r}) + I_3\mathbf{B}_3(\mathbf{r})$$

Planar EM Simulation Basics

- Z_{ij} represents the EM interaction between B_i and B_j
- Solution for interaction matrix equation yields surface currents $$J(r) = \sum_{j=1}^{N} I_j B_j(r)$$



- Decomposing Green's dyadic in the MPIE

$$\overline{\overline{G}}(r,r') = j\omega G^A(r,r')\ddot{I} - \frac{1}{j\omega}\nabla[G^V(r,r')\nabla'] + Z_s\delta(r-r')\ddot{I}$$

- And substituting above into eqn (2) yields

$$Z_{i,j} = R_{i,j} + j\omega L_{i,j} + \frac{1}{j\omega C_{i,j}}$$

With

$$Z_{ij}^L = j\omega L_{ij}(\omega) = \iint_{S_i} dS \iint_{S_j} dS'\, G_m(\omega, r-r')B_i(r)\cdot B_j(r')$$

$$Z_{ij}^C = \frac{1}{j\omega C_{ij}(\omega)} = \iint_{S_i} dS \iint_{S_j} dS'\, G_e(\omega, r-r')\nabla\cdot B_i(r)\nabla\cdot B_j(r')$$

$$Z_{ij}^R = R_{ij}(\omega) = Z_s(\omega)\iint_{S_i} dS \iint_{S_j} dS'\, \delta(r-r')B_i(r)\cdot B_j(r')$$

Planar EM Simulation Basics

Method of Moments

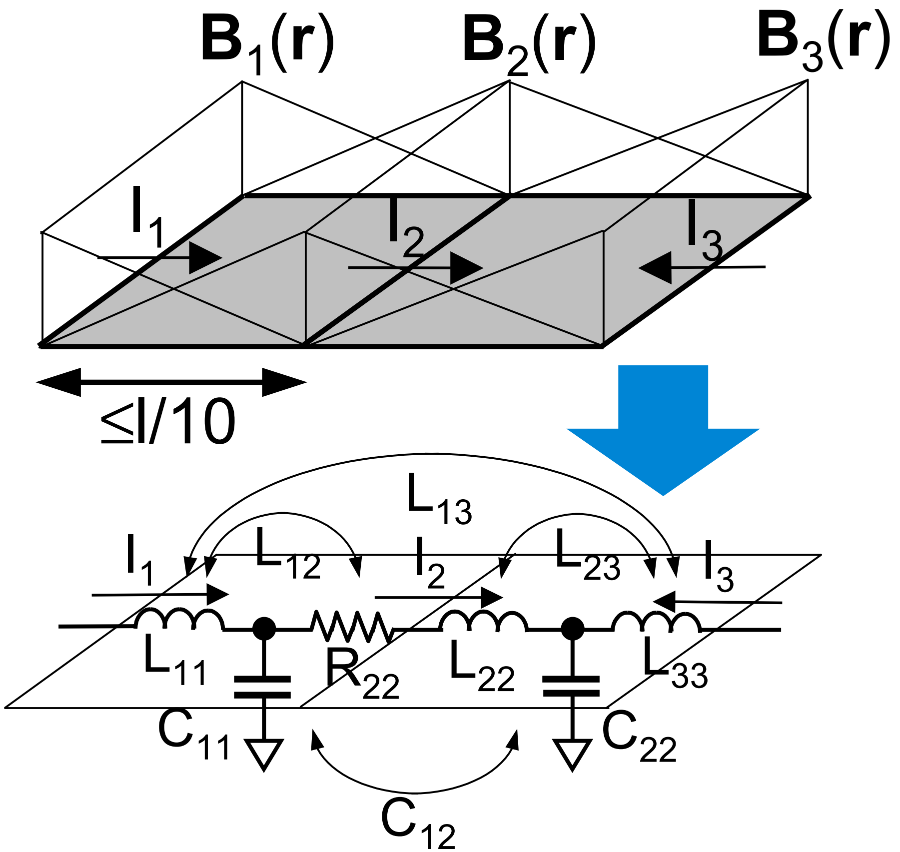
Maxwell's Equations

Matrix Equation

[Z].[I]=[V]

Equivalent Circuit

$[Z] = [R] + jw[L] + 1/jw\ [C]^{-1}$



Planar EM Simulation Basics

Full Wave Approach:

- The electric and magnetic Greens functions follow from Maxwell's equations which include coupling,radiation and dispersion.

- The Green's functions and hence the inductors and capacitors are complex and frequency dependent

For Example in the free space

$$G_m(\omega, r - r') = \frac{j\omega\mu_0}{4\pi|r - r'|} e^{-jk_0|r-r'|}$$

$$G_e(\omega, r - r') = \frac{1}{j\omega\varepsilon_0 4\pi|r - r'|} e^{-jk_0|r-r'|}$$

Can be expanded in Taylor series

$$k_0 = \omega\sqrt{\varepsilon_0\mu_0}$$

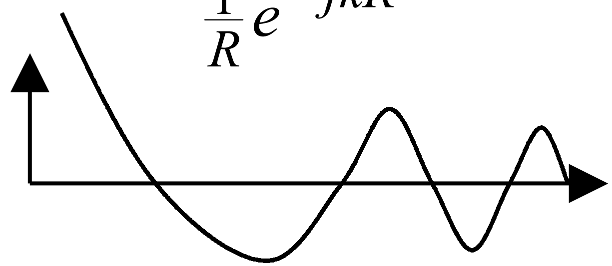
- The above can be expanded in a Taylor series, to accommodate approximations as in the next section.

Momentum versus MomentumRF

Fullwave versus Quasi-Static:

Fullwave EM

$$\frac{1}{R} e^{-jkR}$$



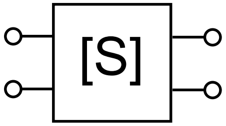
Maxwell's Equations

Matrix Equation

[Z].[I]=[V]

Equivalent Circuit

$$[Z] = [R] + jw[L(w)] + 1/jw\,[C(w)]^{-1}$$



- **Fullwave electric & magnetic Green's functions**
- **Includes space and surface radiation**
- **[L(w)] & [C(w)] are complex and frequency dependent**
- **[Z(w)] matrix reload CPU intensive**

Planar EM Simulation Basics

Quasi-static approach

- The electric and magnetic Greens functions follow from magnetostatic and electrostatic solution of Maxwell's equations

- For the free space

$$G_m(\omega, r - r') = \frac{j\omega\mu_0}{4\pi |r - r'|}$$

$$G_e(\omega, r - r') = \frac{1}{j\omega\varepsilon_0 4\pi |r - r'|}$$

- Equivalent L and C that follow from above will be real frequency independent and do not include HF wave effects, the radiation.

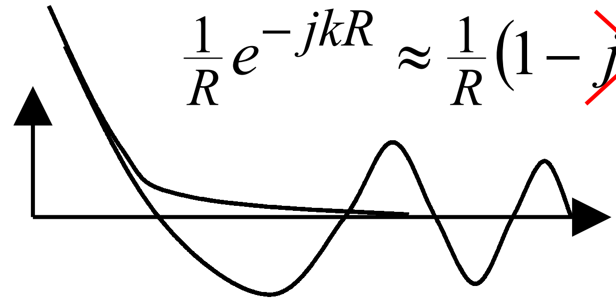
- As long as the electrical length of the circuit is not significant both fullwave and quasi-static approaches give similar results.

Momentum versus MomentumRF

Fullwave versus Quasi-Static: Quasi-Static

Quasi-Static EM

$$\frac{1}{R}e^{-jkR} \approx \frac{1}{R}(1 - jkR + \ldots)$$



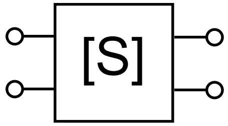
Maxwell's Equations

Matrix Equation

$[Z_o].[I]=[V]$

Equivalent Circuit

$[Z_o] = [R] + jw[L_o] + 1/jw\ [C_o]^{-1}$



- **Electro- and magneto-static Green's functions**
- **Near field / low freq approximation**
  - $L(w) = L_0 + L_1 wR + L_2(wR)^2 + \ldots$
  - $C(w) = C_0 + C_1 wR + C_2(wR)^2 + \ldots$
- **Neglects far field radiation**
- **$[L_0]$ & $[C_0]$ are real and frequency independent**
- **$[Z_0]$ matrix reload very fast**

Momentum versus MomentumRF

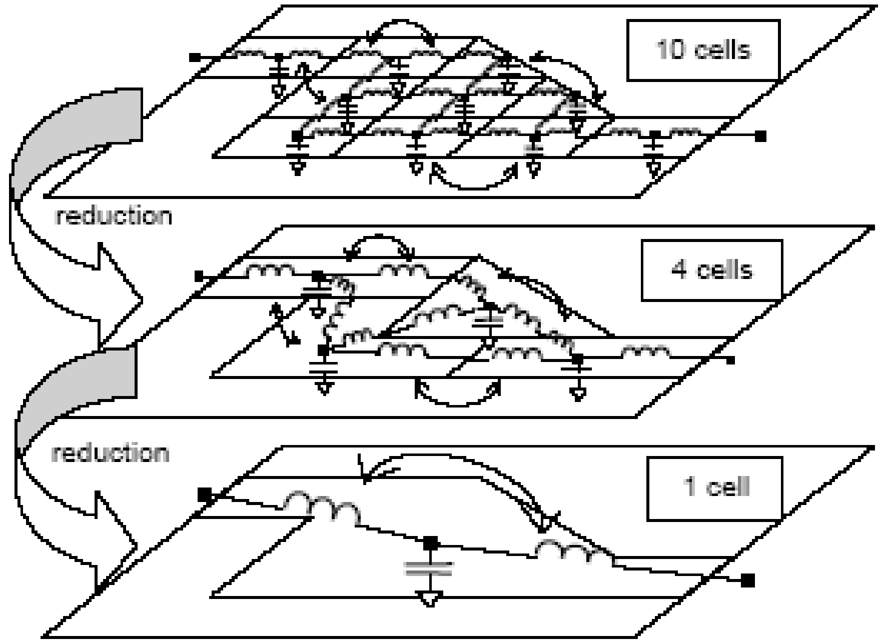
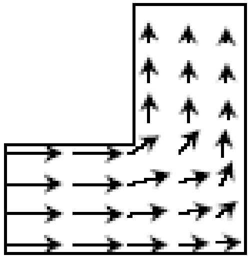
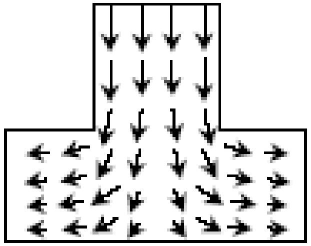


Figure 2. Mesh reduction and corresponding EM equivalent network



(a) L-shaped cell



(b) T-shaped cell

Momentum versus MomentumRF: A Snapshot

Momentum MW features:

- Full-Wave EM Simulation
- ~~Rooftop~~ Basis Function
  Star/Loop*
- Rectangular and Triangular Cells
  OR Polygonal*
- For most passive geometry
- Full accuracy for all circuit sizes
- No inherent upper frequency limit
- Potential ~~instability~~ at f < kHz to MHz
  Results stable down to DC*
- Port Calibration
- Box and Waveguide inclusion
- Includes all radiation modes
- Display 2D and 3D Radiation Patterns
- Improved simulation performance*

*** = NEW in 2003C**

Momentum RF features:

- Quasi-Static EM Simulation
- Star/Loop Basis Functions
- Polygonal cells
  OR Rectangular/Triangular*
- Best for geometrically complex designs
- For electrically small designs ($\leq \lambda/2$)
- Upper frequency depends on size
- Results stable down to DC
- Port Calibration
- ~~No Box~~ / Waveguide Modes
  Box and Waveguide inclusion*
- For designs that don't radiate
- No Radiation Patterns
- Great for 1st pass results, even for large designs ($> \lambda/2$)
- Simulation time and memory decrease by ~ 10X-25X

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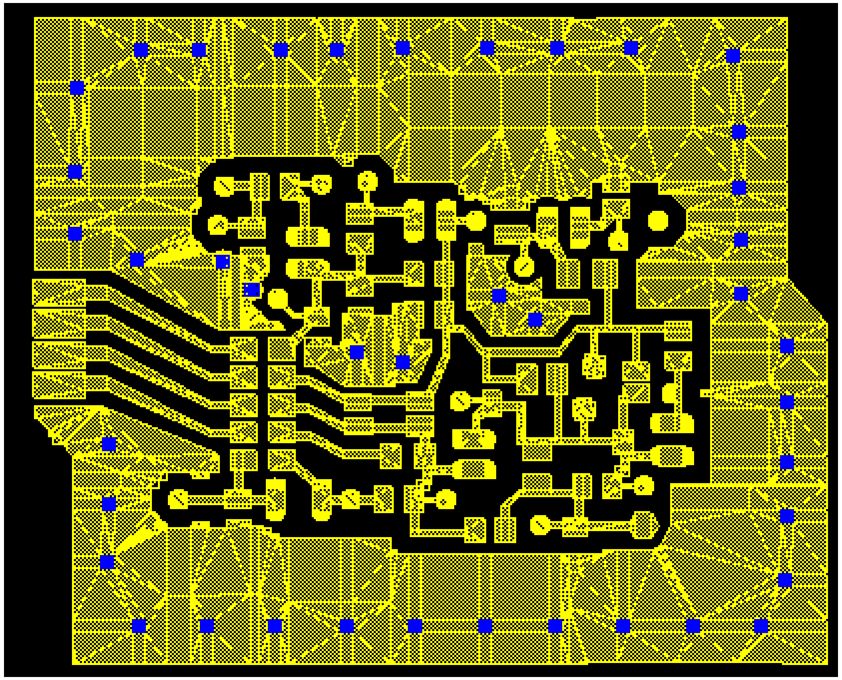
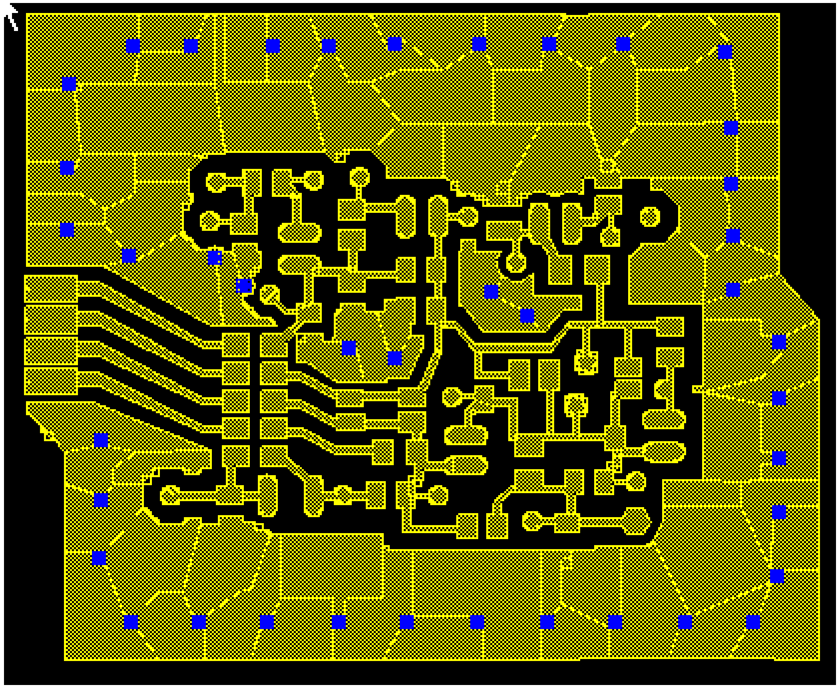
Momentum versus MomentumRF

Momentum

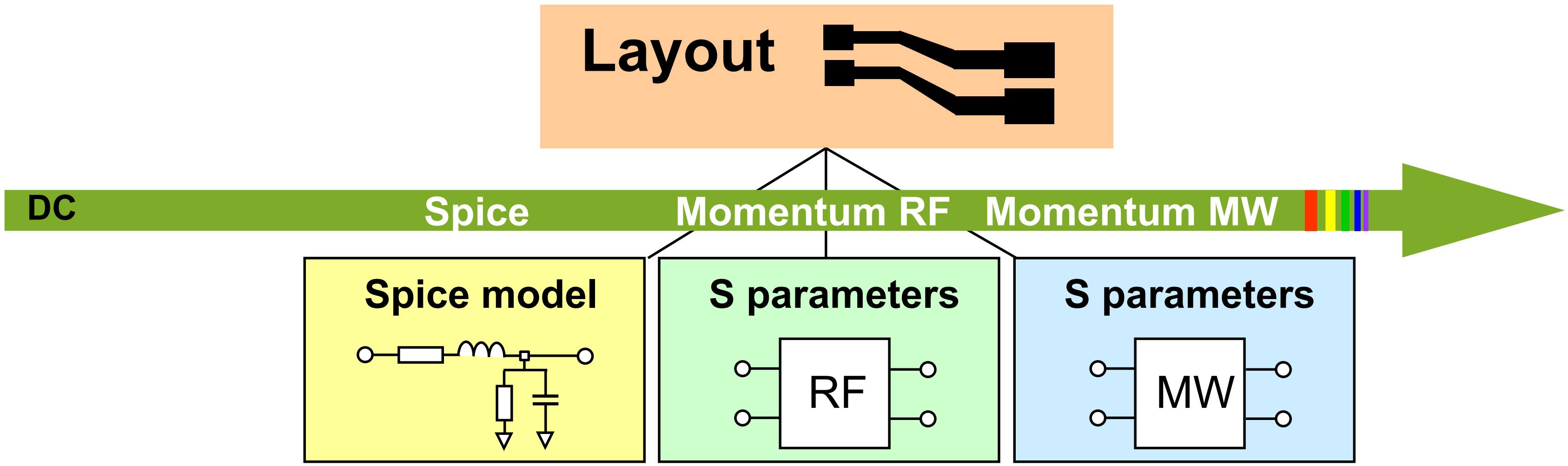


Momentum RF



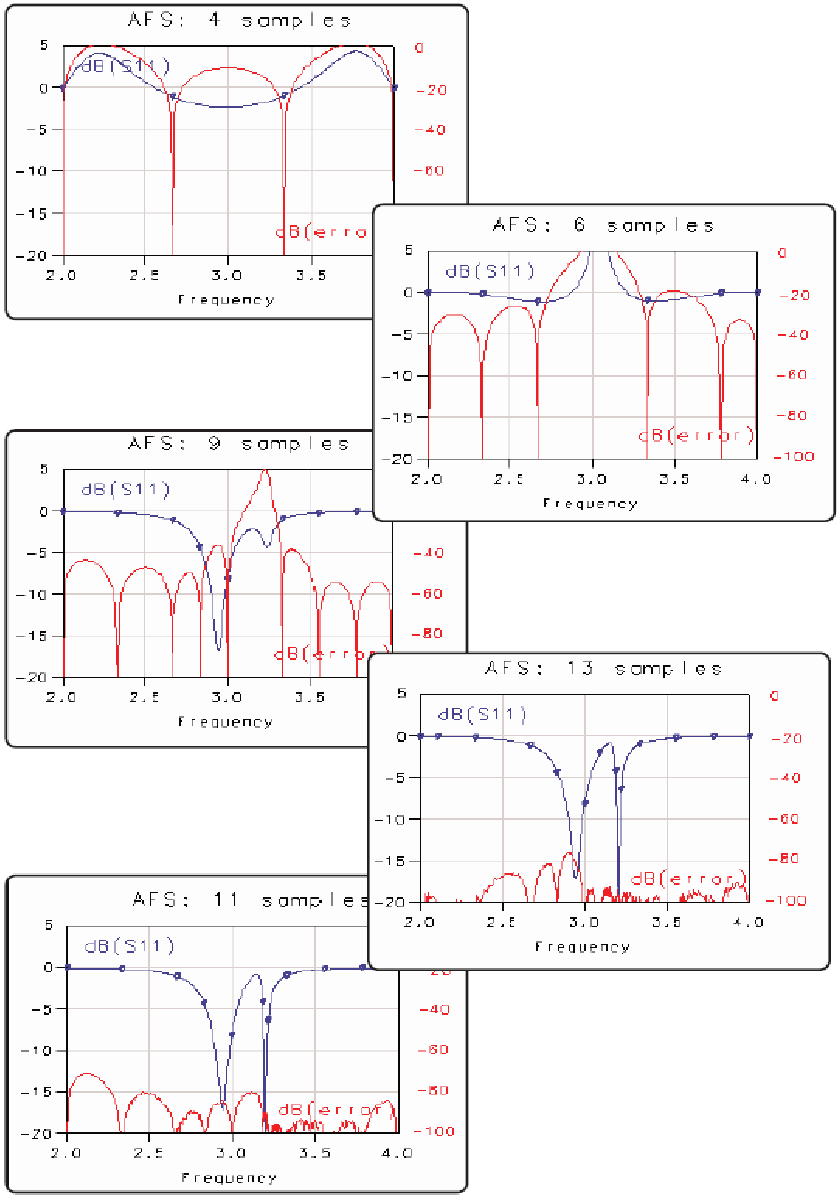
Momentum versus MomentumRF

A Summary of Effects Included



Effect	Spice	Momentum RF	Momentum MW
• quasi-static inductance	√	√	√
• quasi-static capacitance	√	√	√
• DC conductor loss (s)	√	√	√
• DC substrate loss (s)	√	√	√
• dielectric loss (tan d)		√	√
• skin effect loss		√	√
• substrate wave radiation			√
• space wave radiation			√

Adaptive Frequency Sampling



The Adaptive Frequency Sampling process of selecting frequencies is illustrated here. The S-parameter response and the error function are shown.

Multiple Adaptive Parameter Sampling Is similar excepting that the sampling Is done in the parameter domain.

Adaptive Frequency Sampling

Adaptive Frequency Sampling (AFS)

-Automatic selection of key frequencies
-Interpolates all S-parameter data using a rational fitting model

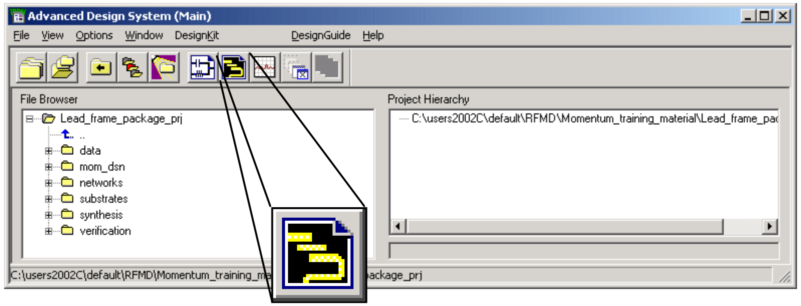
$$S(f) = \frac{A + B*f + C*f^2 + \ldots}{K + L*f + M*f^2 + \ldots}$$

the_16.gif

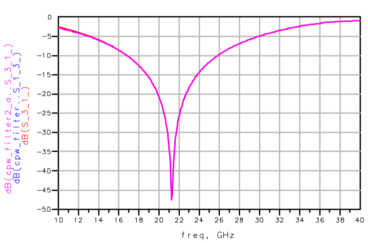
Simple Answer to Convergence

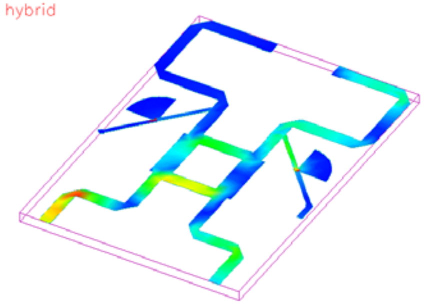
AFS has converged unless it tells you that it hasn't converged (e.g., when the max number of points that you specified was too low)

How is Momentum used ?

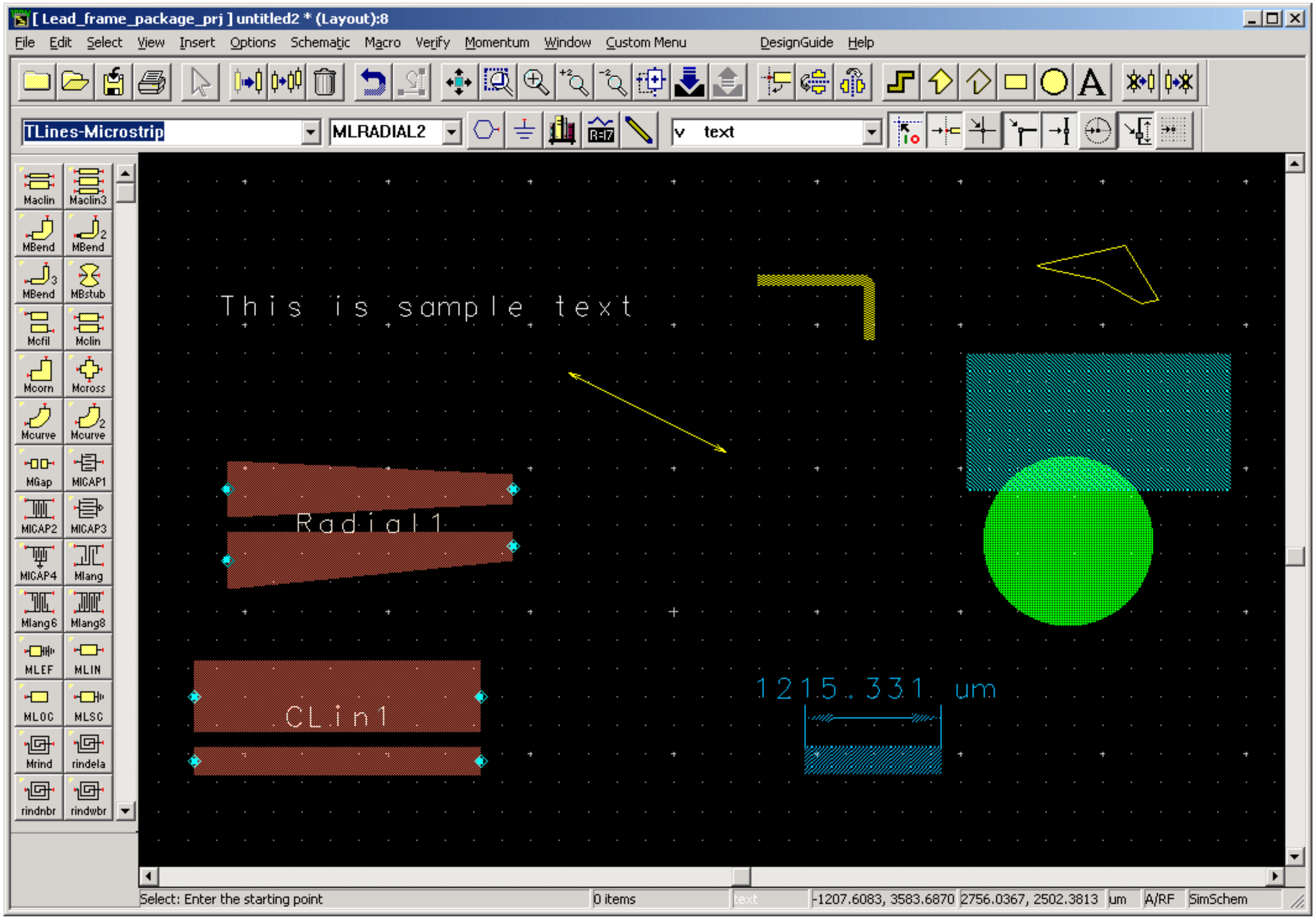


- **<u>Layout driven</u>**
  1. **Created entirely within layout,**
  2. **Schematic-to-Layout translation, OR**
  3. **Import – (DXF, GDSII, etc.)**
- **Momentum interface within ADS Layout**
  - **Mode > Substrate/Metallization > Port > Mesh > Simulation > Component > Optimization**
- **Outputs**
  - **S-parameters**
  - **Current visualization**





Creating artwork in Layout

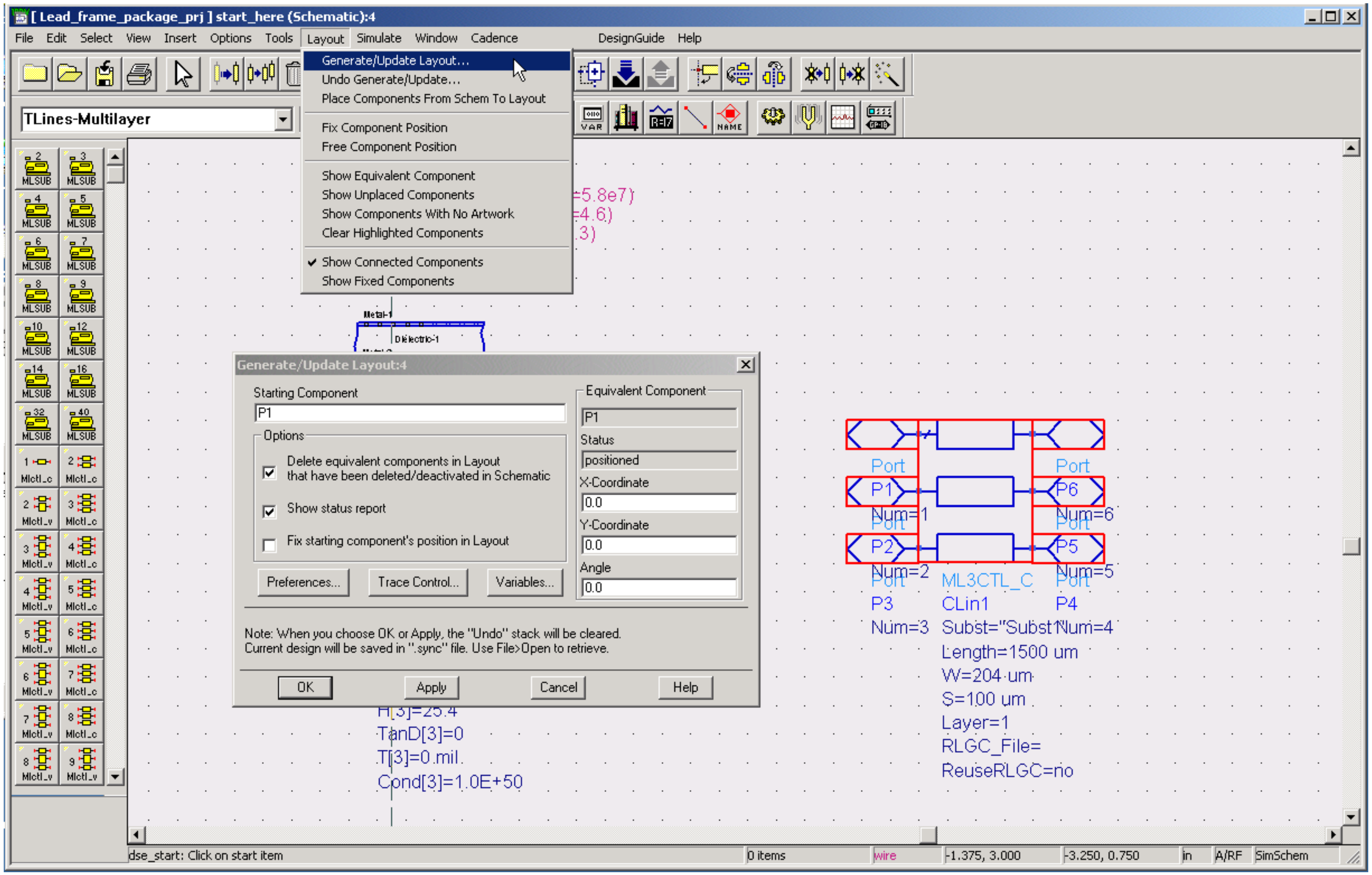


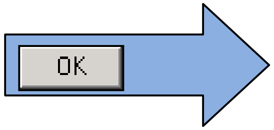
Created entirely within layout

Schematic-to-Layout translation

Import – (DXF, GDSII, etc.)

Creating/importing artwork in Layout





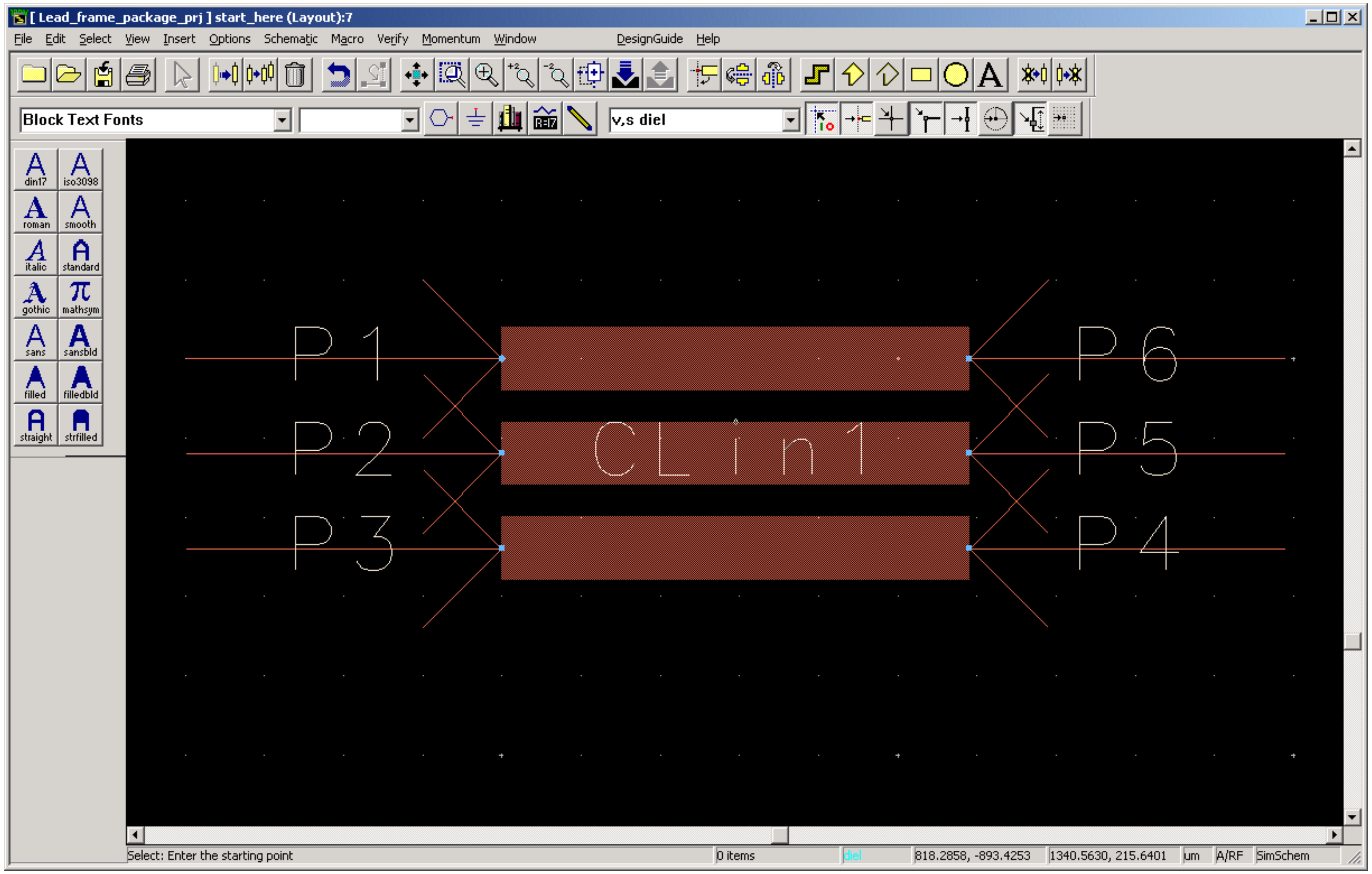
Created entirely within layout

Schematic-to-Layout translation

Import – (DXF, GDSII, etc.)

Creating/importing artwork in Layout

- Created entirely within layout
- **Schematic-to-Layout translation**
- Import – (DXF, GDSII, etc.)



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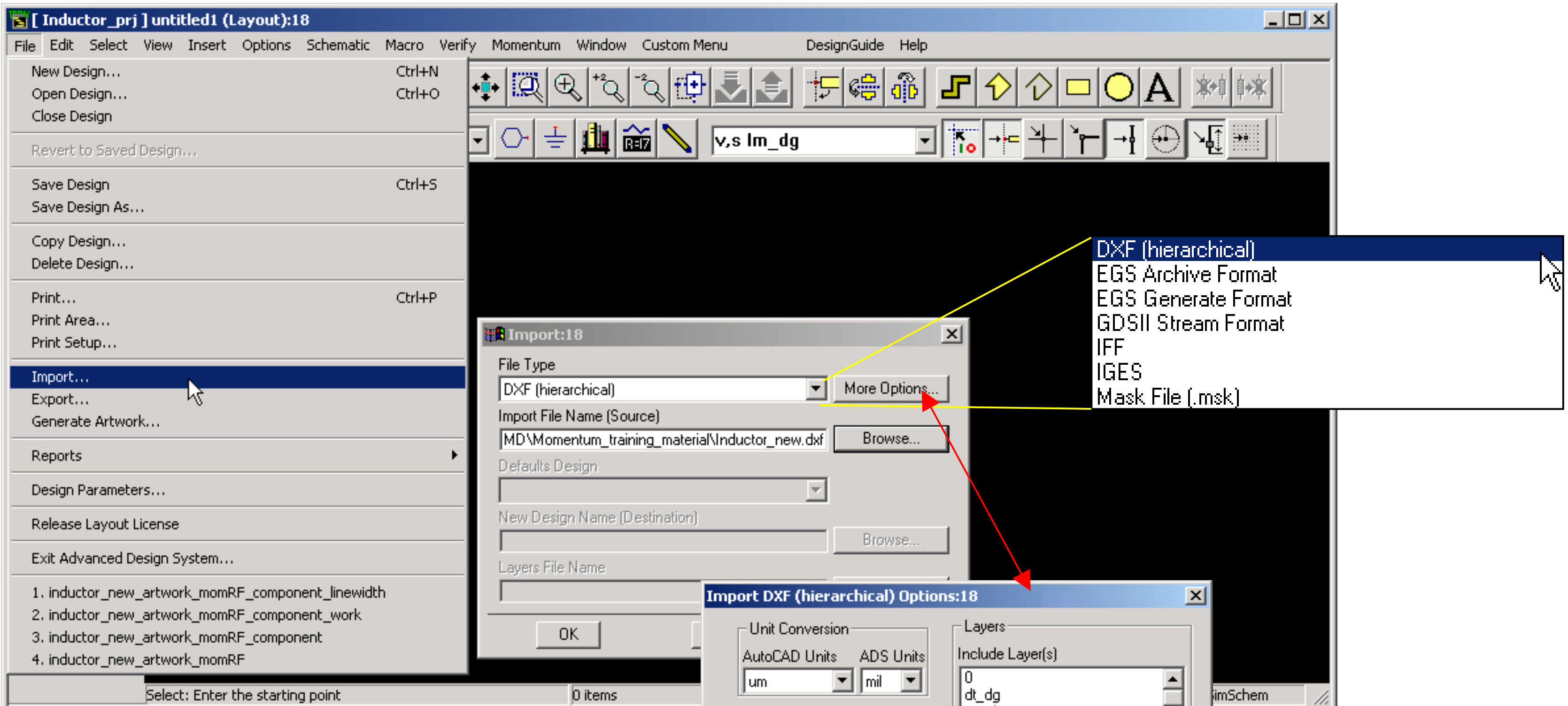
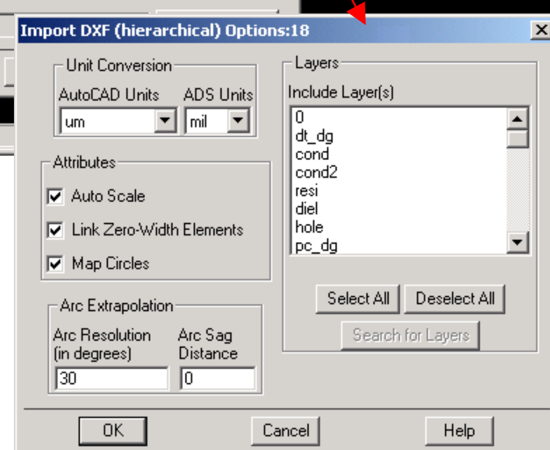
Importing artwork in Layout





Created entirely within layout

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Importing artwork in Layout

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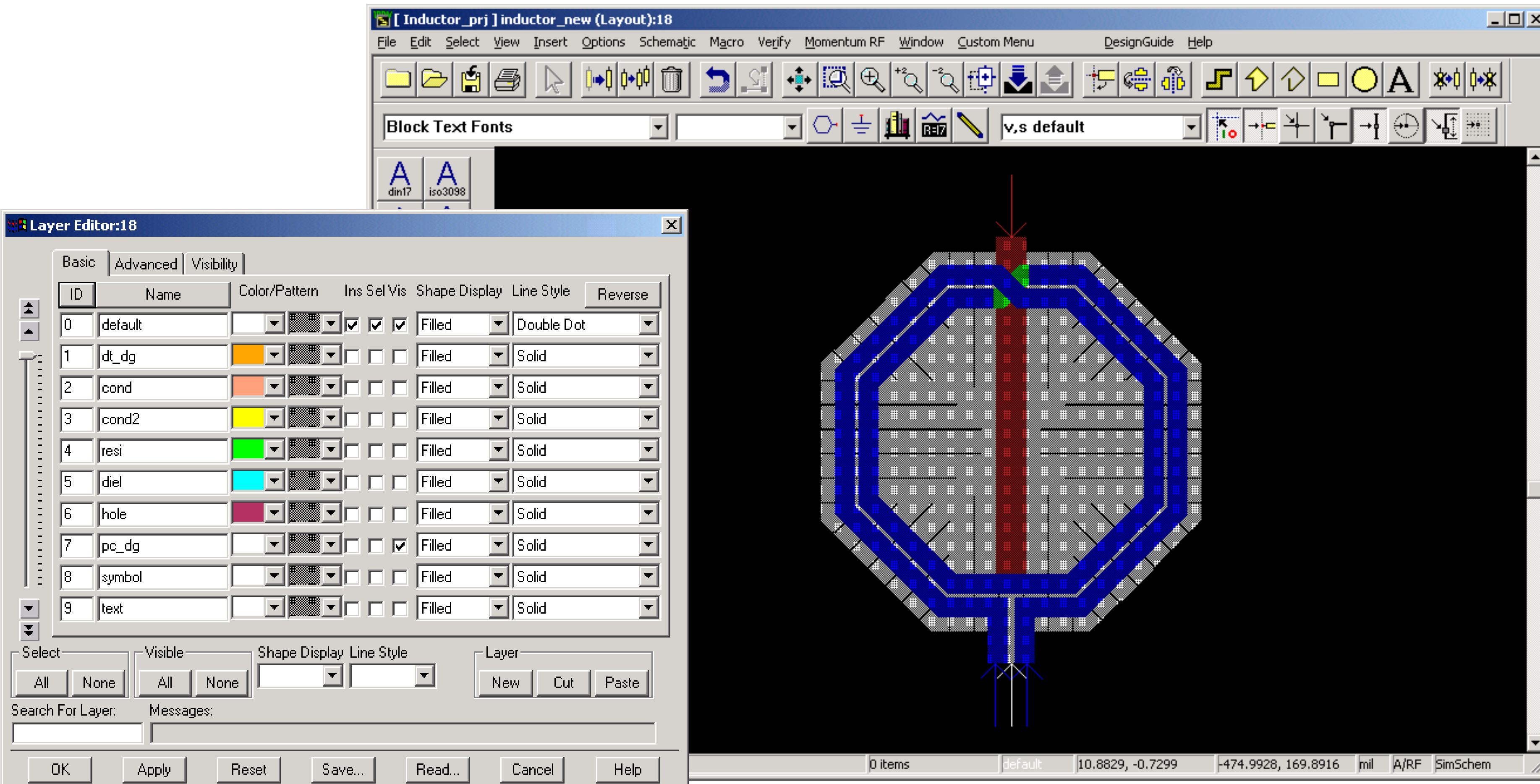
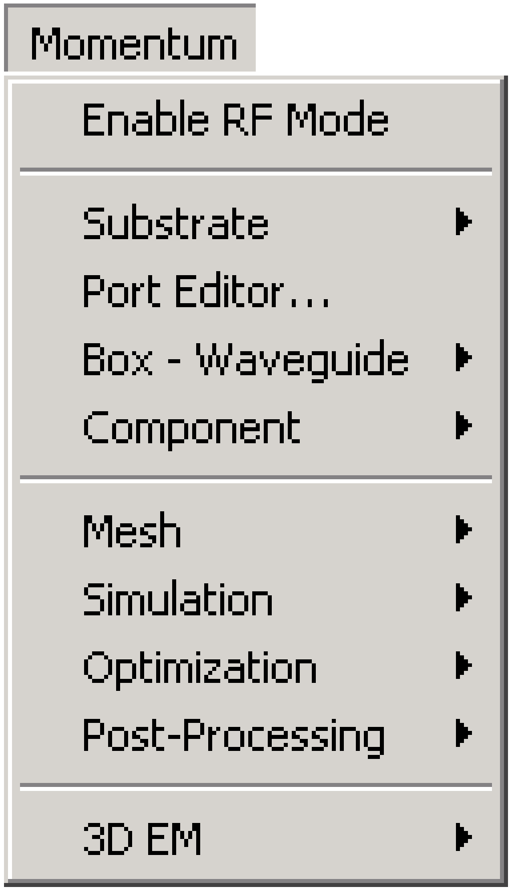


Using Momentum



Solution process

- Select Mode
- Substrate definition
- Port Setup
- Mesh Generation
- Planar Solve
- Display Results

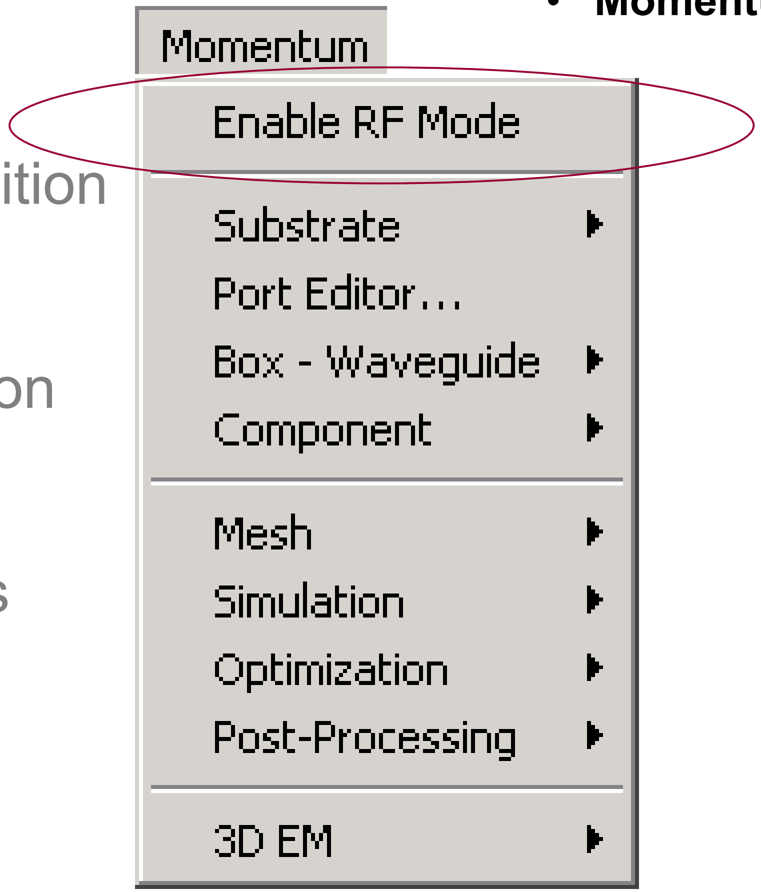
- **Enable regular Momentum or Momentum RF**
- **Define Substrate and Metallization (pre-compute option)**
- **Modify the type and impedance of ports**
- **Describe a possible Substrate enclosure**
- **Create/modify Momentum Component to be used in EM/circuit co-simulation or co-optimization**
- **Define Mesh parameters (pre-compute option)**
- **Setup and Perform a Momentum simulation (planar solve)**
- **Setup and Perform a Momentum optimization (geometric perturbation based)**
- **Display Visualization (S-parameters, current density, transmission line parameters) and Radiation patterns**
- **Export 3D files for HFSS**

Using Momentum: Selecting the Analysis Mode

Click this submenu to toggle the analysis mode

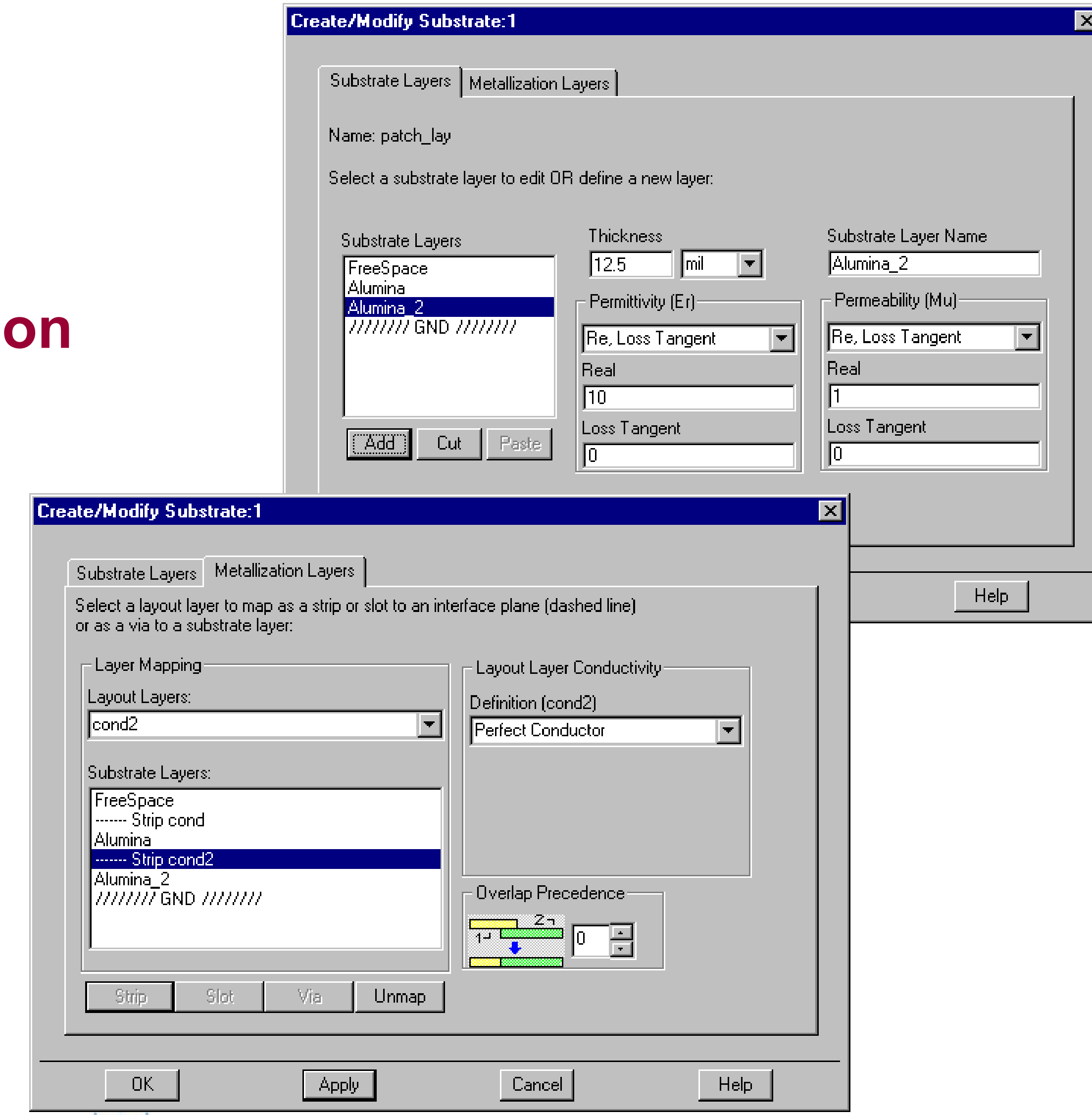
- Momentum → MomentumRF
- MomentumRF → Momentum

- **Solution process**
  - **Select Mode**
  - Substrate definition
  - Port Setup
  - Mesh Generation
  - Planar Solve
  - Display Results



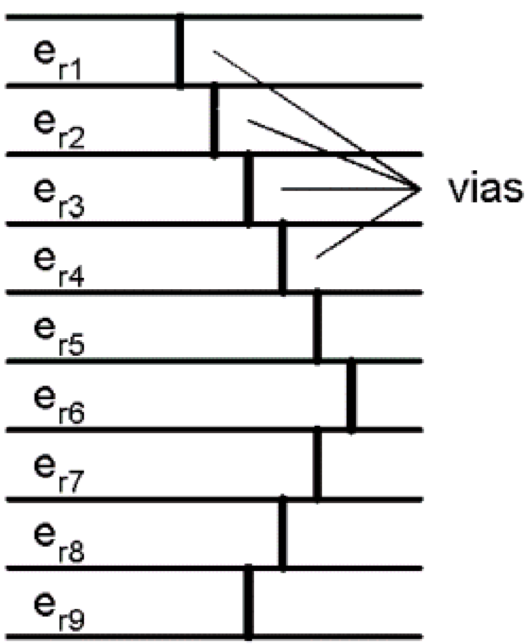
Using Momentum: Creating Substrate Stack-ups and Mapping Layout Layers as Metallization Layers

- **Solution process**
  - Select Mode
  - **Substrate definition**
  - Port Setup
  - Mesh Generation
  - Planar Solve
  - Display Results



Using Momentum: Creating Substrate Stack-ups and Mapping Layout Layers as Metallization Layers

Greens Function Substrate Calculation Time



Substrate Calculation Time:

Example - 9 conductor layers with 9 vias

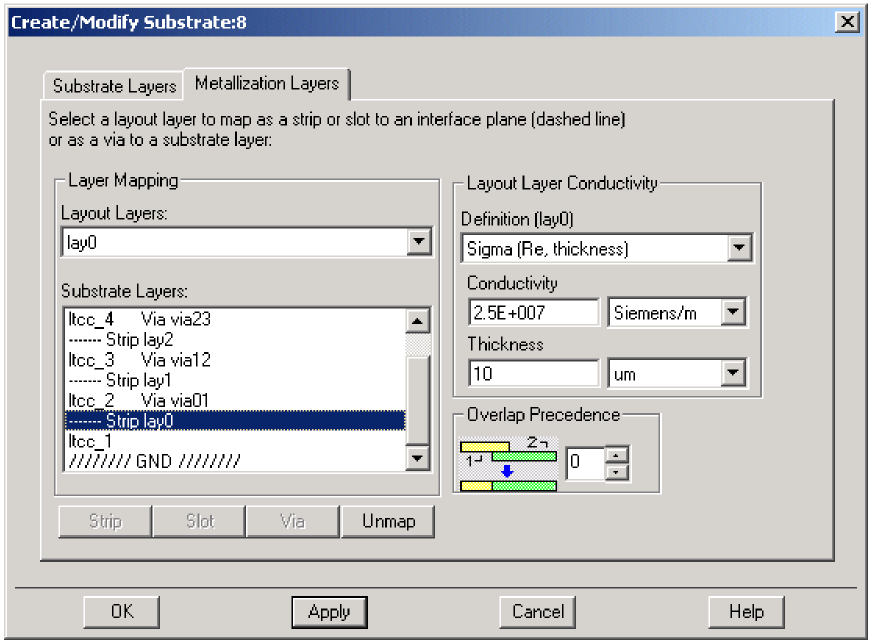
9 conductors + 9 vias = 18 metals

They are all coupled, so 18 * 18 = 324 different types of coupling must be computed and stored.

This is 324 times slower than the calculation for a single metal

Using Momentum: Creating Substrate Stack-ups and Mapping Layout Layers as Metallization Layers

A note on layout layer conductivity



Conductivity defined as:

1. **Perfect Conductor (lossless)**
2. **σ (Real, Imaginary)**
3. **σ (Real, thickness)**
4. **Impedance (Real, Imaginary)**

The parameters selected are applied toward a conductor loss algorithm, this does NOT affect the layout thickness

Using Momentum: Creating Substrate Stack-ups and Mapping Layout Layers as Metallization Layers:

Loss Model used in Strip Conductors

- Momentum treats all conductors as having zero thickness. However, the conductivity and thickness can be specified to approximate frequency dependent losses in the metallization patterns.
- Momentum uses a complex surface impedance for all metals that is a function of conductor thickness, conductivity, and frequency.
  - At low frequencies, current flow will be approximately uniformly distributed across the thickness of the metal. Momentum uses this minimum resistance and an appropriate internal inductance to form the complex surface impedance.
  - At high frequencies, the current flow is dominantly on the outside of the conductor and Momentum uses a complex surface impedance that closely approximates this skin effect.
  - At intermediate frequencies, where metal thickness is between approximately two and ten skin depths, the surface impedance transitions between those two limiting behaviors.
- This surface impedance is added to the Method of Moments approach that is used for Momentum in general.
- The formula used is a combination of a high-frequency conductivity and a low-frequency bulk resistivity. The formula is such that both approaches (LF bulk behavior → HF surface impedance) transition seamlessly.
- The formula is:
  - $Z = \coth(\gamma) * Zc$
    - where Zc = the HF impedance and $\coth(\gamma)$ is the correction for finite thickness
  - $Zc = 0.5 * \mathrm{sqrt}(j * \mu_0 * \omega/(\sigma + j * \varepsilon_0 * \omega))$
  - $\gamma = 0.5 * \mathrm{thickness} * \mathrm{sqrt}(j * \mu_0 * \omega * (\sigma + j * \varepsilon_0 * \omega))$
    - where $\omega = 2 * \pi * f$
    - and σ = conductivity = 1/resistivity [in Siemens/meter]
- The meshing density can affect the simulated behavior of a structure. A more dense mesh allows current flow to be better represented and can slightly increase the loss. This is because a more uniform distribution of current for a low density mesh corresponds to a lower resistance

"thick conductors" Can also be treated

Using Momentum

- **Solution process**
  - Select Mode
  - Substrate definition
  - **Port Setup**
  - Mesh Generation
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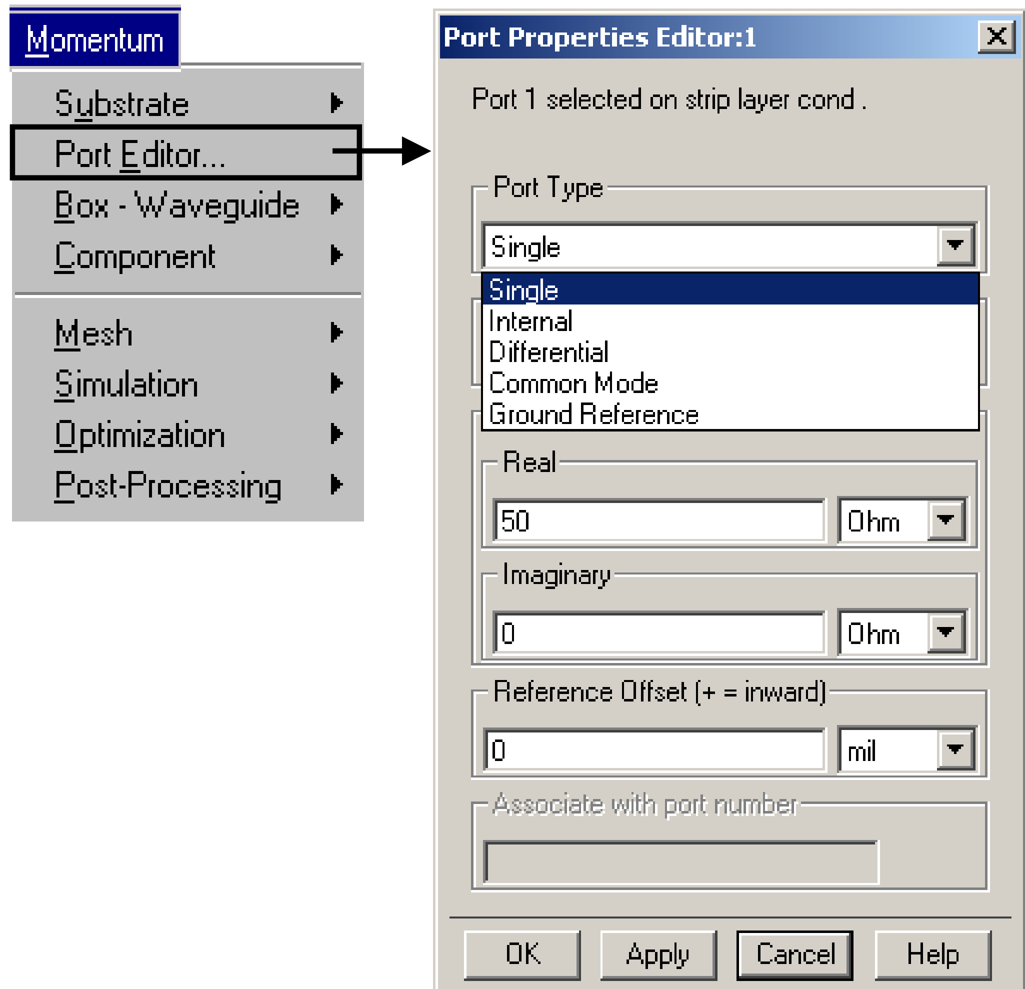
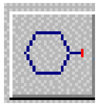
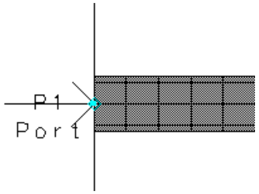
  - Display Results



Placing and Defining Ports

Description of Momentum Port Types



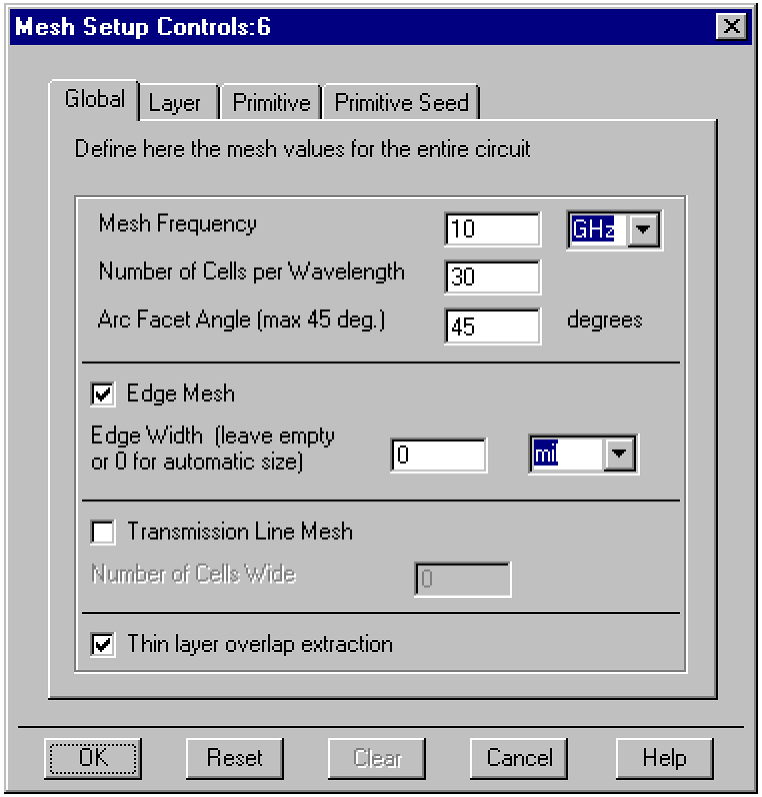


Port Type	General Description	Placement	Type of layer
• **Single** (default)	Calibrated to remove mismatch at port boundary (might also call this a transmission line port)	Edge	Strip or Slot
•**Internal**	Not calibrated (might also call this a direct excitation port)	Edge or Surface	Strip
• **Differential**	Two ports with opposite polarity	Edge	Strip
• **Coplanar (CPW)**	Two ports with opposite polarity	Edge	Slots
• **Common Mode**	Two ports with the same polarity	Edge	Strip
• **Ground Ref.**	An explicit ground reference for a Single or Internal port.	Edge or Surface	Strip

CPW NOTE: For **finite ground planes**, use Ground Reference ports and Internal port on center conductor.

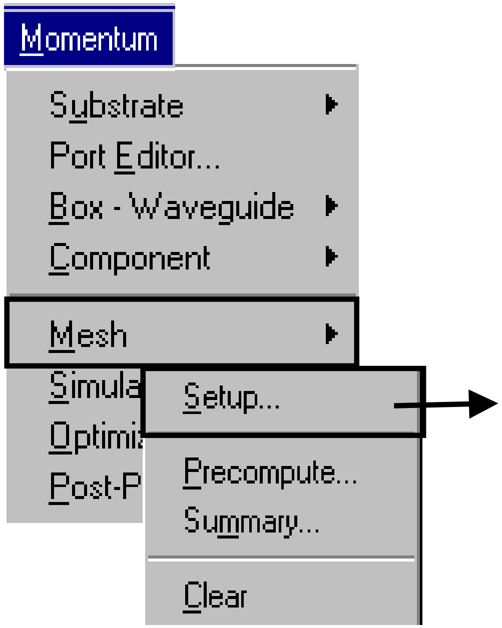
Details of Momentum

- **Solution process**
  - Select Mode
  - Substrate definition
  - Port Setup
  - **Mesh Generation**
  - Planar Solve
  - Display Results

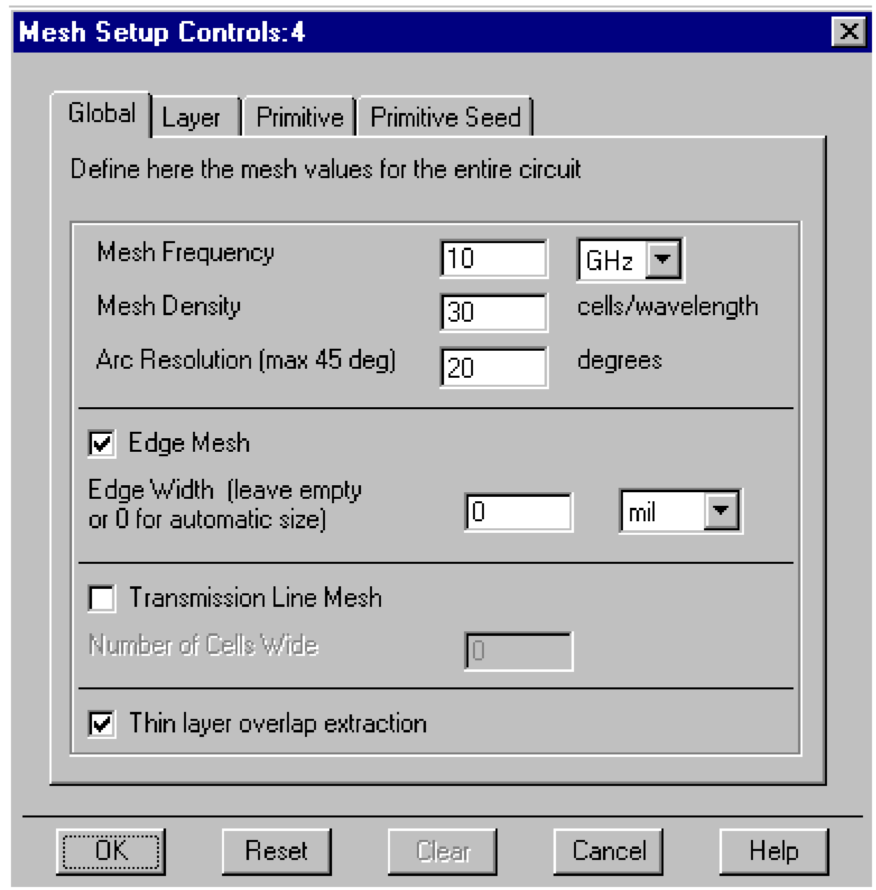


Defining Mesh Parameters

Mesh Setup Control



Global mesh is the default. But you have choices.



In general, small patterns are more accurate but take more time to solve.

Defining Mesh Parameters

Global Mesh example with Edge Mesh

1 - Port

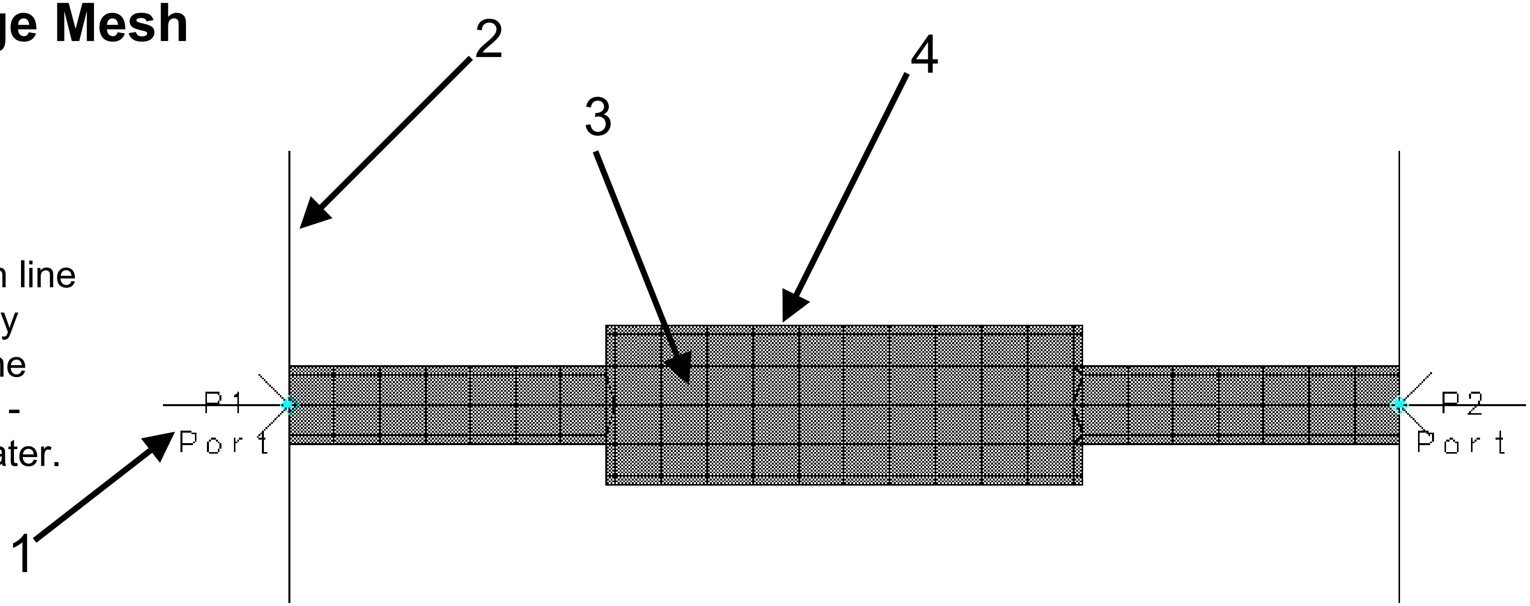
2 - Calibration Line

3 - Mesh

4 - Edge Mesh

Here, the cell size is the same for all parts of the geometry, except for the edges around each primitive.

The calibration line is automatically drawn when the port is defined - more on this later.



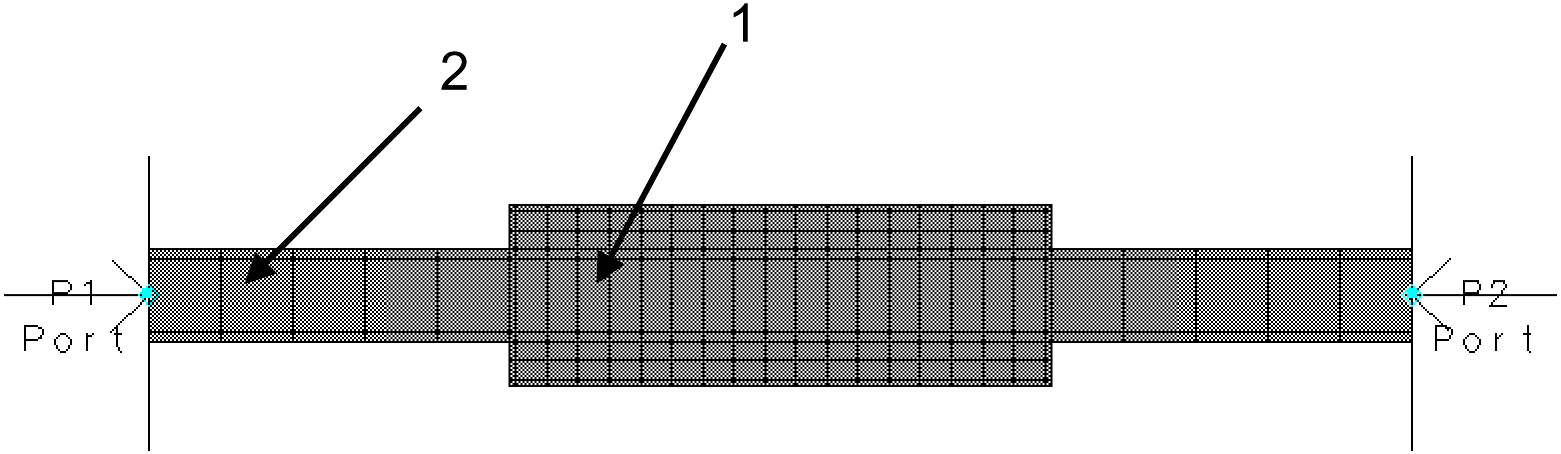
NOTE: You can view the mesh, ports, and reference line before simulating and make adjustments if desired.

Defining Mesh Parameters

Primitive Mesh example

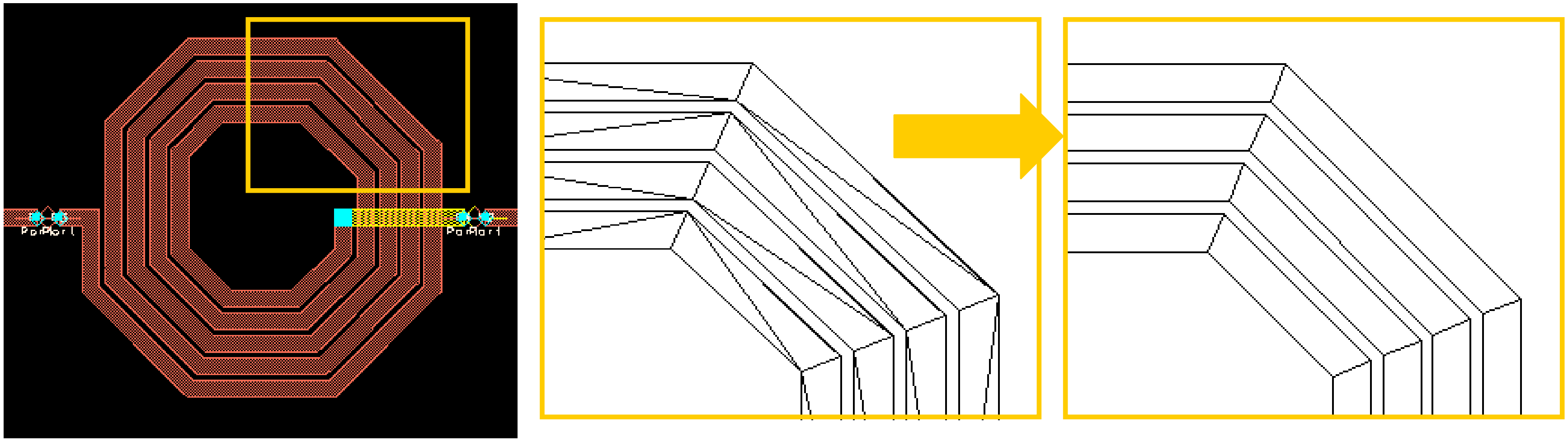
You can combine primitive mesh, layer mesh, and global mesh.

The center ***primitive*** of this geometry has a different mesh (50 cells/wavelength) than the two outside geometries (20 cells/wavelength).

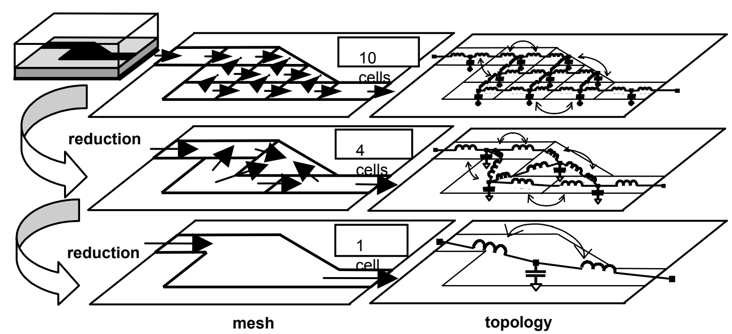


Mesh: Momentum versus MomentumRF

Momentum RF & Polygon Mesh



- Meshing complex geometries with POLYGONAL cells
- Eliminates “slivery” triangles
- Eliminates redundant R,L,C elements
- Uncompromised accuracy for RF frequencies
- Strongly reduced computer memory
- Strongly reduced computation time



Using Momentum

Method of Moments

- **Solution process**
  - Select Mode
  - Substrate definition
  - Port Setup
  - Mesh Generation
  - **Planar Solve**
  - Display Results

Maxwell's Equations

⬇

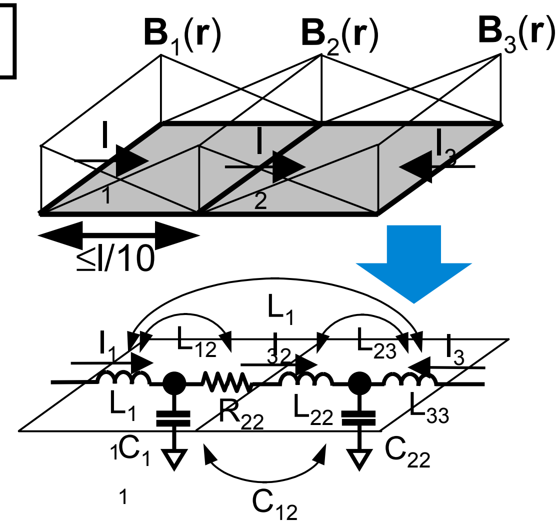
Matrix Equation

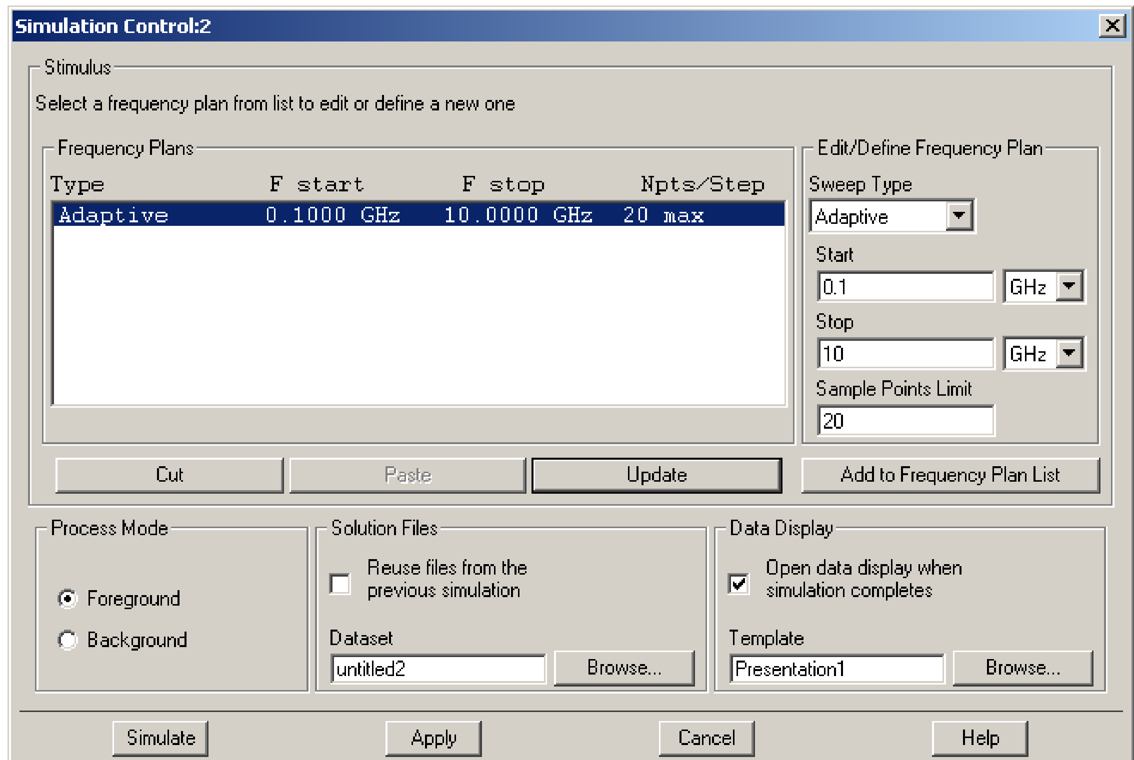
[Z].[I]=[V]

⬍

Equivalent Circuit

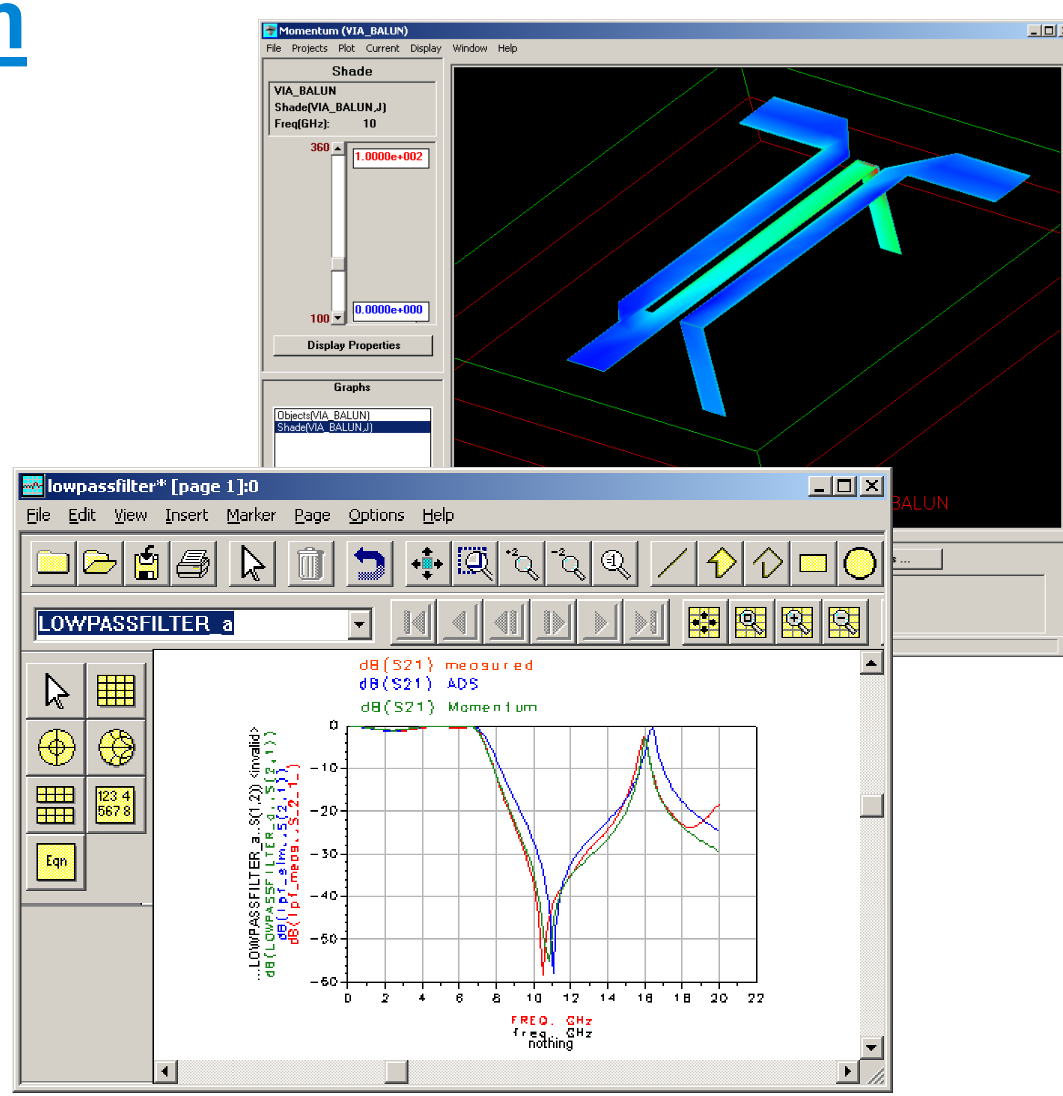
$[Z] = [R] + jw[L] + 1/jw\,[C]^{-1}$





Using Momentum

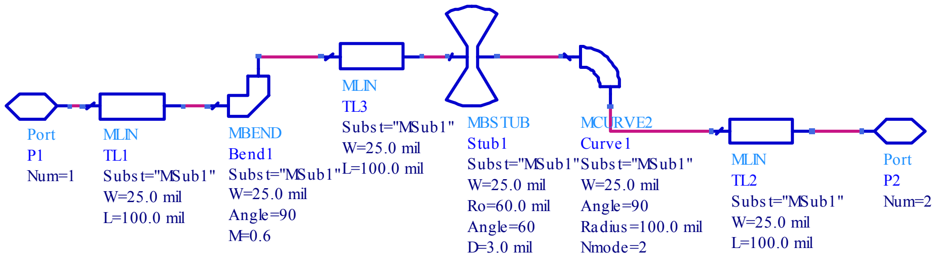
- **Solution process**
  - Select Mode
  - Substrate definition
  - Port Setup
  - Mesh Generation
  - Planar Solve
  - **Display Results**



More on this in the next section…

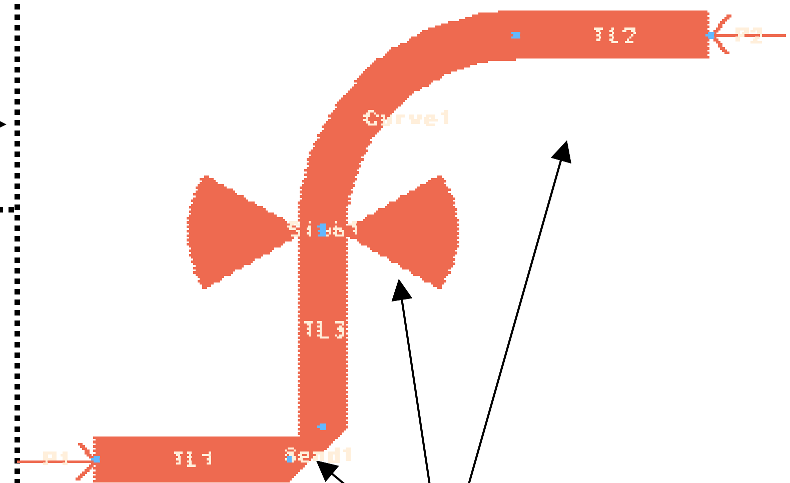
Model Composer : Allows you to create EM model for an electrical component

Create a **Schematic**

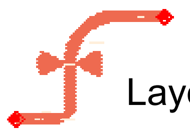


Translate to Layout

Layout



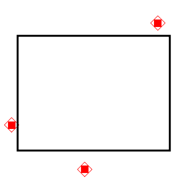
These structures retain parameters. Define the range in which they vary In an EM model. Create **Layout** component



Layout look alike

Ref
test
test_1
ModelType=MW

Or



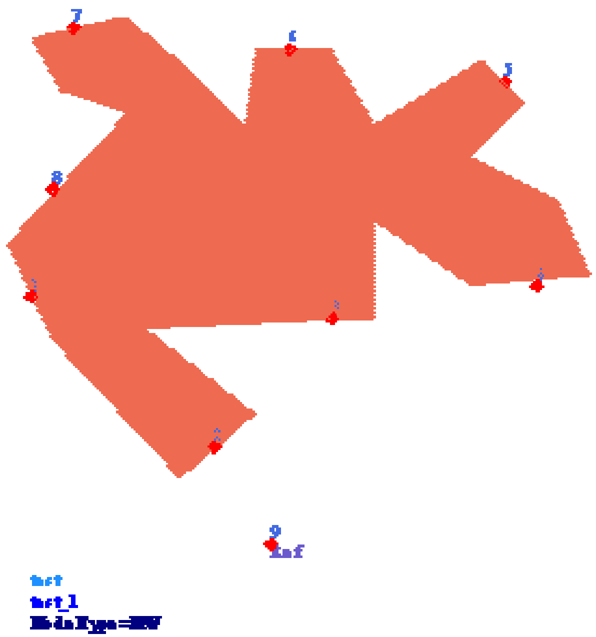
Black Box

test
test_1
ModelType=MW

Place the Layout component In the schematic

Advanced Model Composer: Lets you create EM models for arbitrary shapes

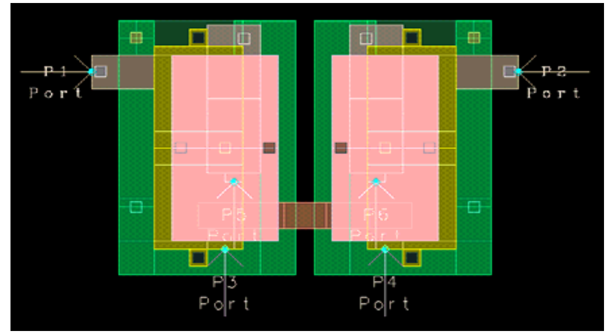
Let this be your most creative network !!!



- Parameterize this network in terms of various geometrical parameters
- Tell the simulator how you want them to vary.
- Perform the EM simulation to create a EM model This creates a design kit using MAPS
- Install the design Kit
- Use the design kit there after in schematics
- You can now Co-simulate and Co-optimize
- You can use all the powerful statistical design tools such as yield optimization, tolerance analysis, design centering etc.

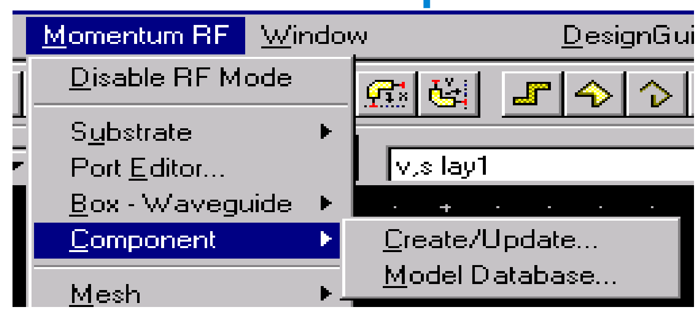
Momentum Component (EM/circuit co-simulation)

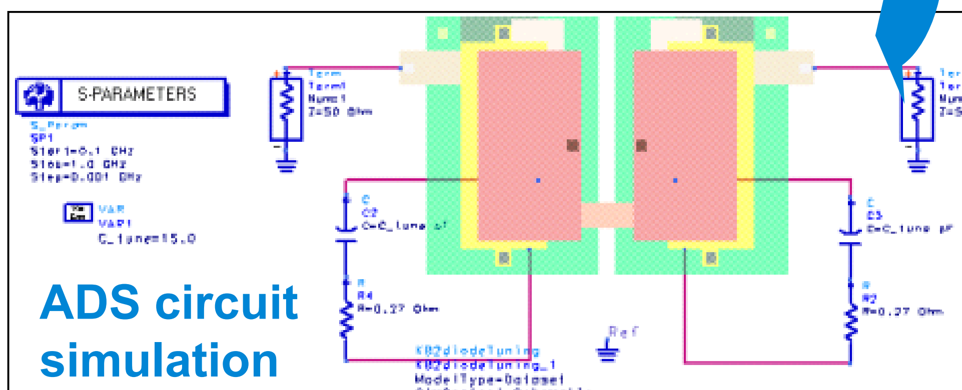
- EM/Circuit co-simulation from the schematic environment
- Transparent integration of electromagnetic simulators at the schematic design level
- Include physical layout parasitics in schematic
- Momentum simulation options accessible from schematic
- Compiled Layout Components listed in project’s hierarchy
- Model database for reuse option
- **ADS 2002C: EM/Circuit co-optimization**



Layout setup

Momentum Component



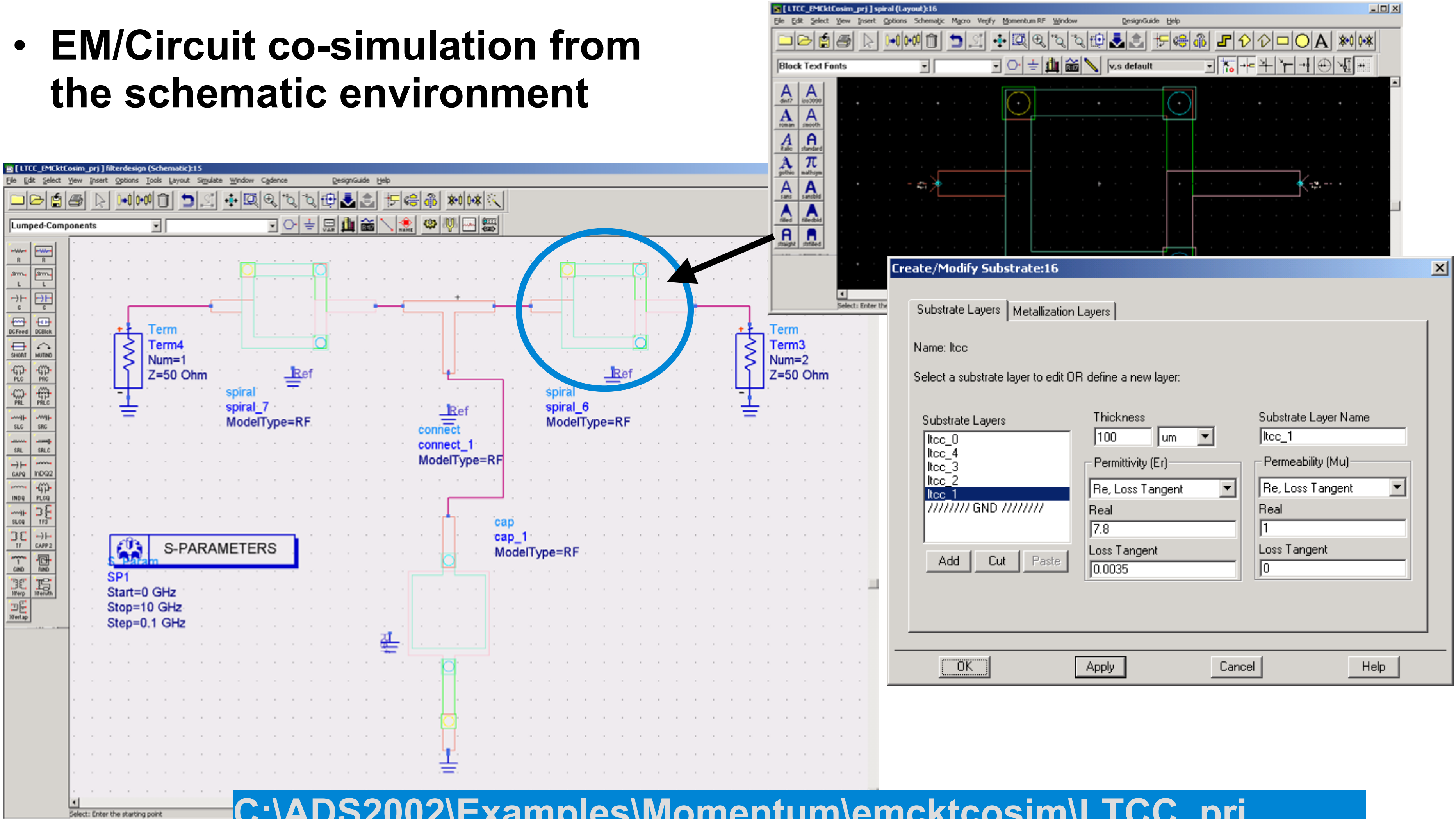


ADS circuit simulation

Momentum Component (EM/circuit co-simulation)

Example included in ADS 2002 & higher

- **EM/Circuit co-simulation from the schematic environment**



C:\ADS2002\Examples\Momentum\emcktcosim\LTCC_prj

Momentum Datasets

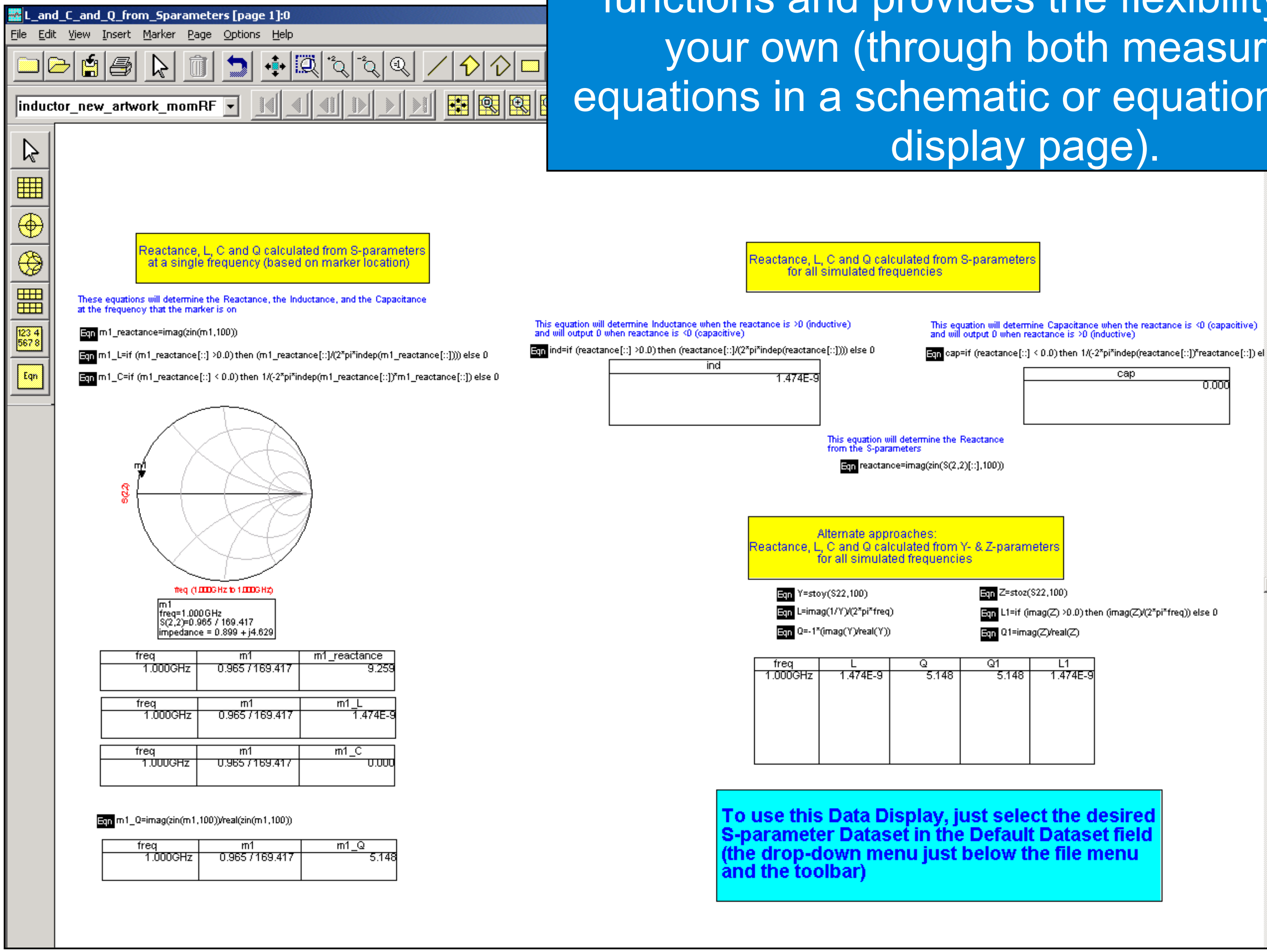
Variables Available in the Standard Dataset

• freq	Independent frequency variable
• GAMMA*n*	Modal propagation constant of port *n* (calculated for single, differential, and coplanar ports only)
• PORTZ*n*	Impedance of Port *n*
• S	S-matrix, normalized to PORTZ*n*
• S(i,j)	S-parameters for each port pairing, normalized to PORTZ*n*
• S_50	S-matrix, normalized to 50 ohms
• S_50(i,j)	S-parameters for each port pairing, normalized to 50 ohms
• S_Z0	S-matrix, normalized to Z0
• S_Z0(i,j)	S-parameters for each port pairing, normalized to Z0 of each port
• Z0n	Characteristic impedance of Port n (calculated for single, differential, and coplanar ports only, others are 50 ohms)

(Note that these are included in the datasets for Momentum simulations but not for MomentumRF)

ADS Data Display: *S-parameters, L, and Q of an Inductor*

Powerful post processing data display allows you to take advantage of countless built-in functions and provides the flexibility to wrote your own (through both measurement equations in a schematic or equations in a data display page).



Momentum Datasets

Variables Available in the Far-field Dataset

- **THETA** — Swept parameter of planar cut
- **PHI** — Swept parameter of conical cut
- **Etheta & Ephi** — Absolute E field strength (V) of theta and phi far-field components
- **Htheta & Hphi** — Absolute H field strength (A) of theta and phi far-field components
- **Elhp & Erhp** — Normalized E field strength of LHCP and RHCP far-field components
- **ARcp** — Axial ratio, derived from LHCP and RHCP far-field components
- **Eco & Ecross** — Normalized E field strength of co and cross polarized far-field comp
- **ARlp** — Linear polarization axial ratio, derived from co and cross polarized far-field components
- **Gain, Directivity** — Gain, Directivity, Efficiency (in %), and Effective area (in m^2) Efficiency, Effective Area
- **Power** — Radiation intensity (in watts/steradian)

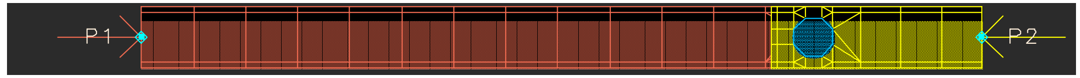
Momentum Visualization

Momentum Visualization Enables You to View and Analyze...

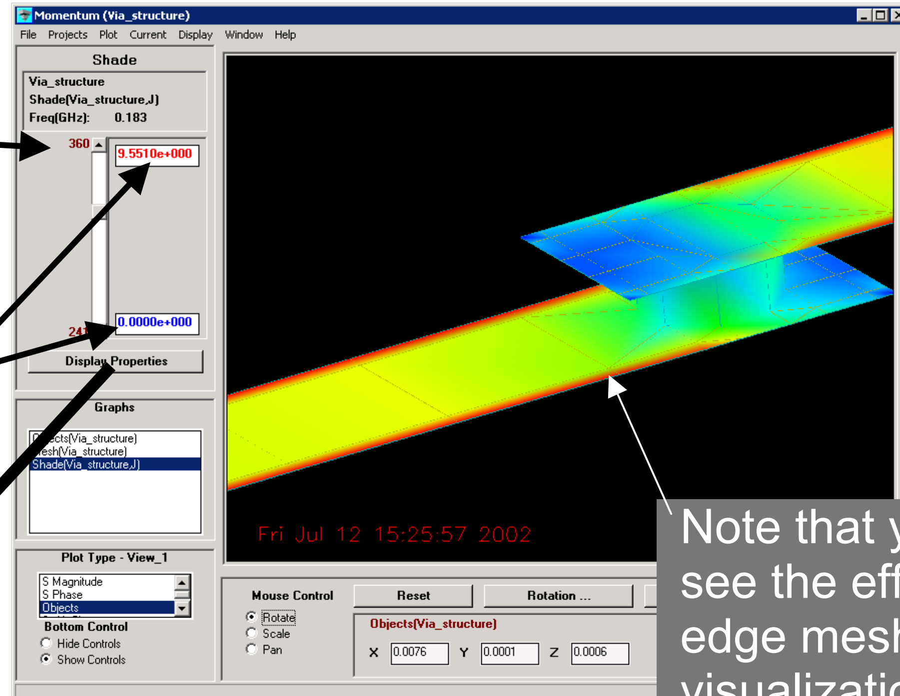
- **Currents (surface currents)**
- **S-parameters (mag, re, im, phase, and dB of S(i,j))**
- **Transmission line data (propagation constant, characteristic impedance)**
- **Far-fields (radiation patterns & axial ratio in 3D and 2D)**
- **Antenna parameters (gain, directivity, pointing angle, etc.)**

Momentum Visualization: *Surface Currents*

When you scroll from 0-360, you are actually varying the phase which illustrates the e^jwt time dependency of the surface currents

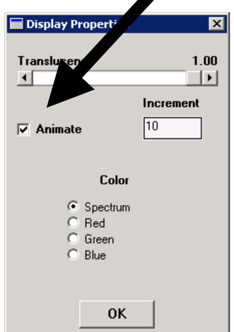


The lower and upper values input into these fields represents the lowest and highest values of the surface current density (A/m) which will be viewed



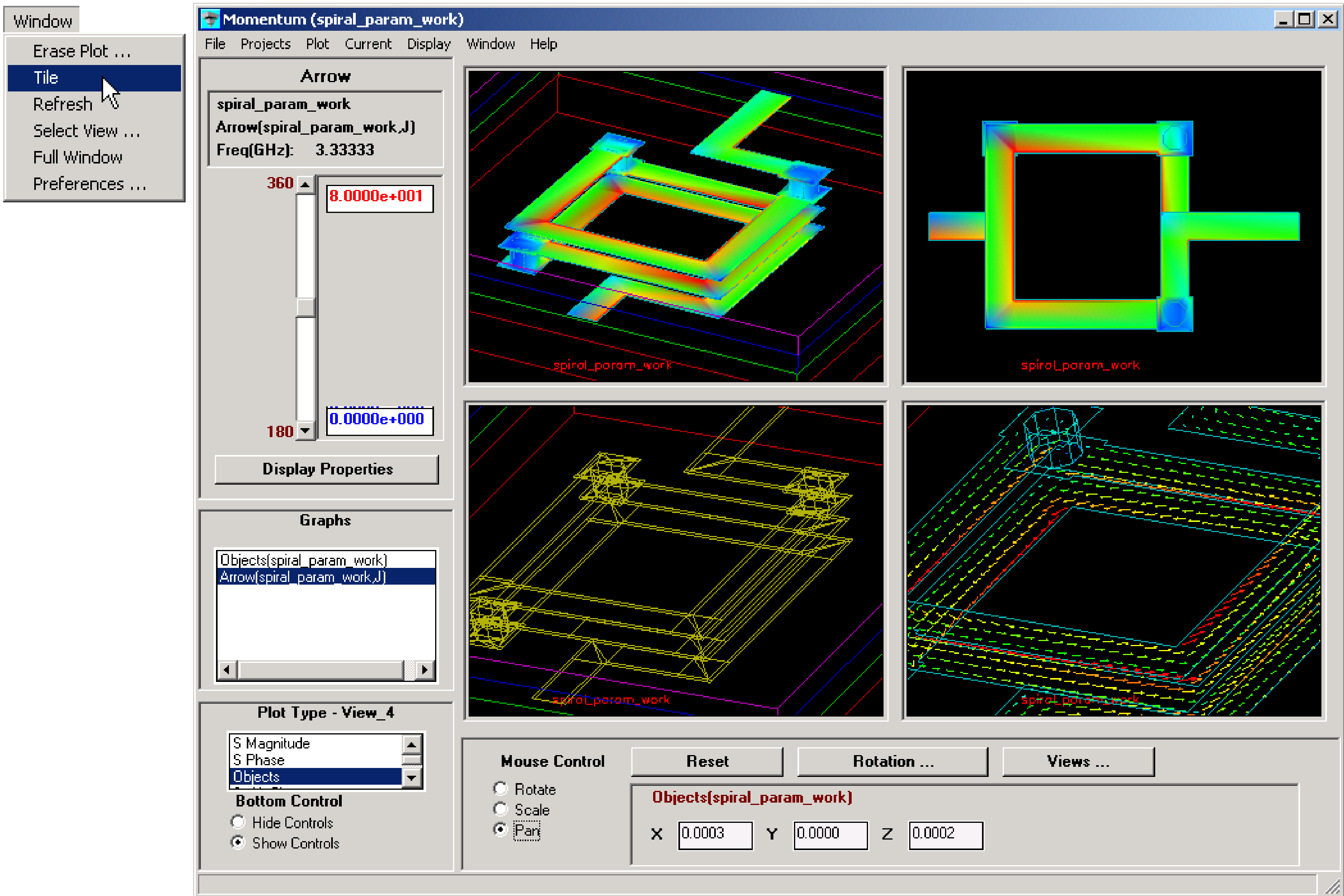
Note that you can also see the effects of an edge mesh in the current visualization (the skin effect is emphasized)

You also have the option to look at the animated currents when click on the Display Properties button



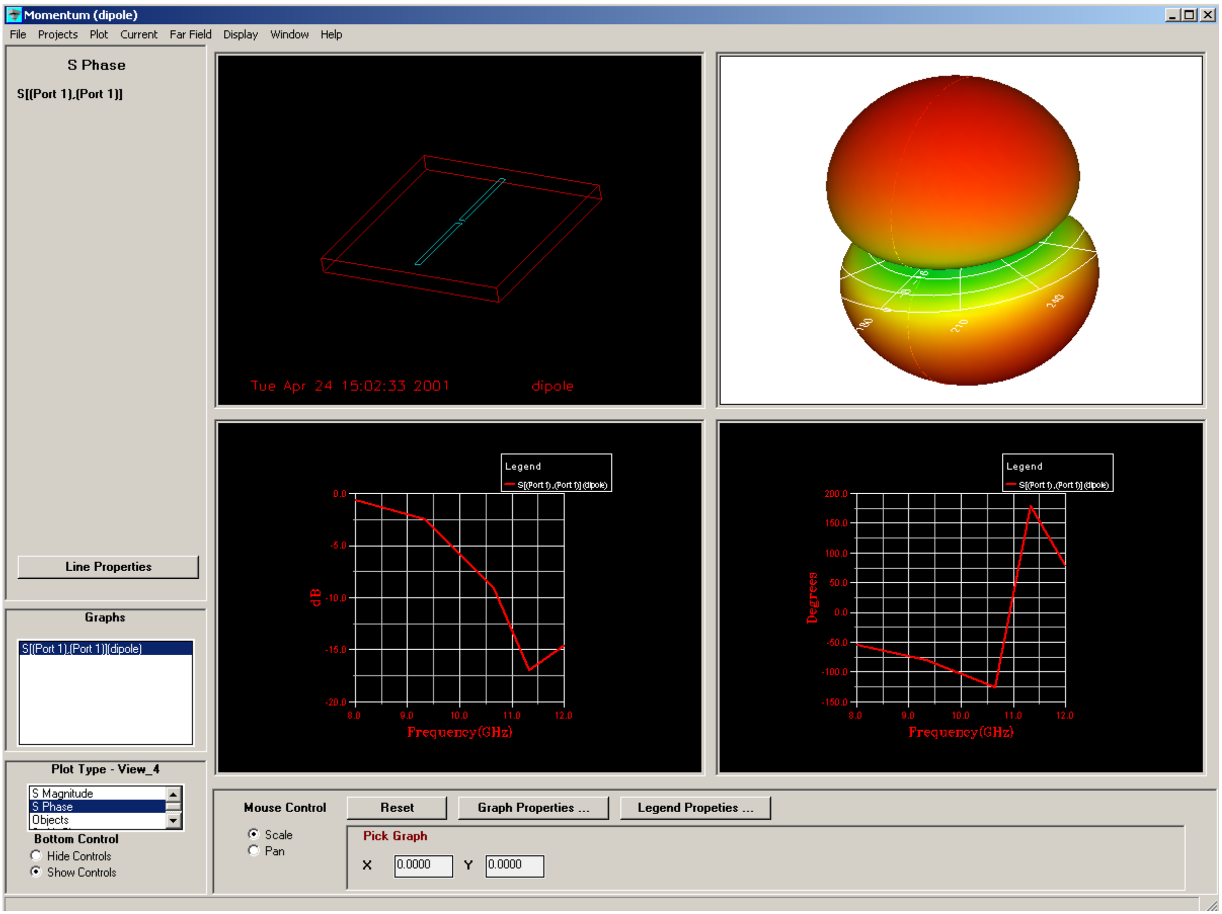
Note: when you are viewing the results for a slot metallization layer, the MAGNETIC currents are plotted instead of the ELECTRIC currents. You will also be viewing the mesh in the slots instead of a mesh on the conductors when viewing the mesh for a slot layer.

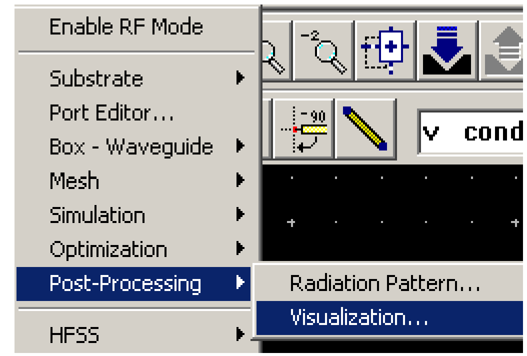
Momentum Visualization: *Surface Currents*



Momentum Visualization:

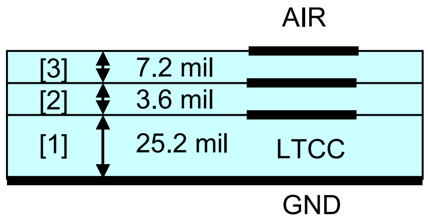
Far-field Radiation Patterns and S-parameters

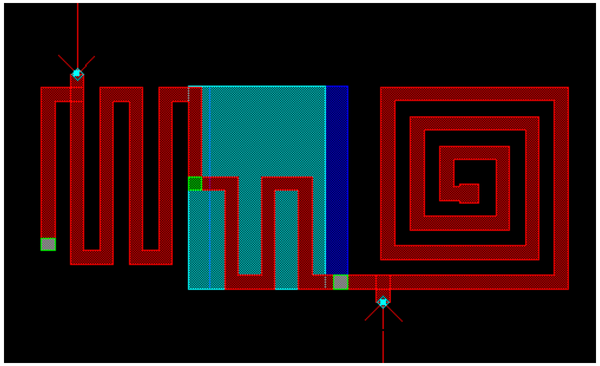


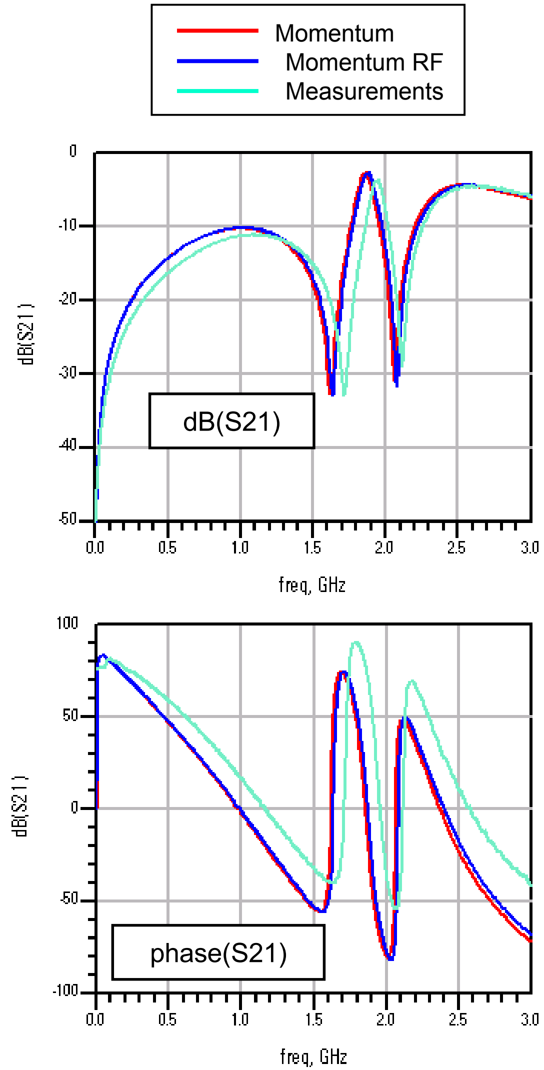


Radiation Patterns are only available with Momentum results, not MomentumRF

LTCC Filter Design







Momentum

Mesh: 20 cells/wavelength, 3 GHz
Frequencies: 14

Matrix size	:	**218**
Process size	:	**14.13 MB**
User time	:	**5 m 14 s**

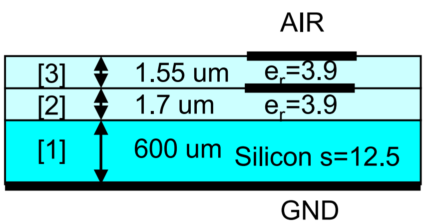
Momentum RF

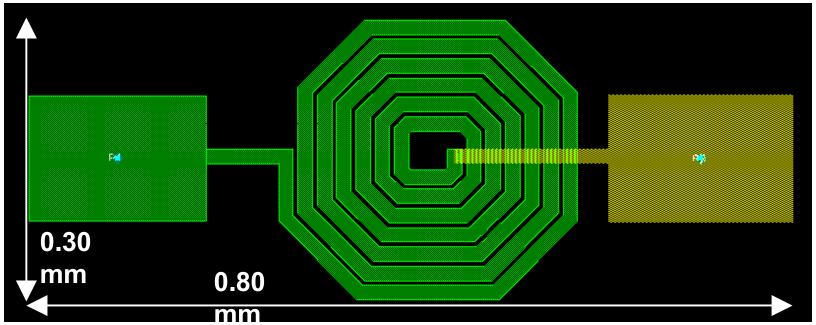
Mesh: 20 cells/wavelength, 3 GHz
Frequencies: 10

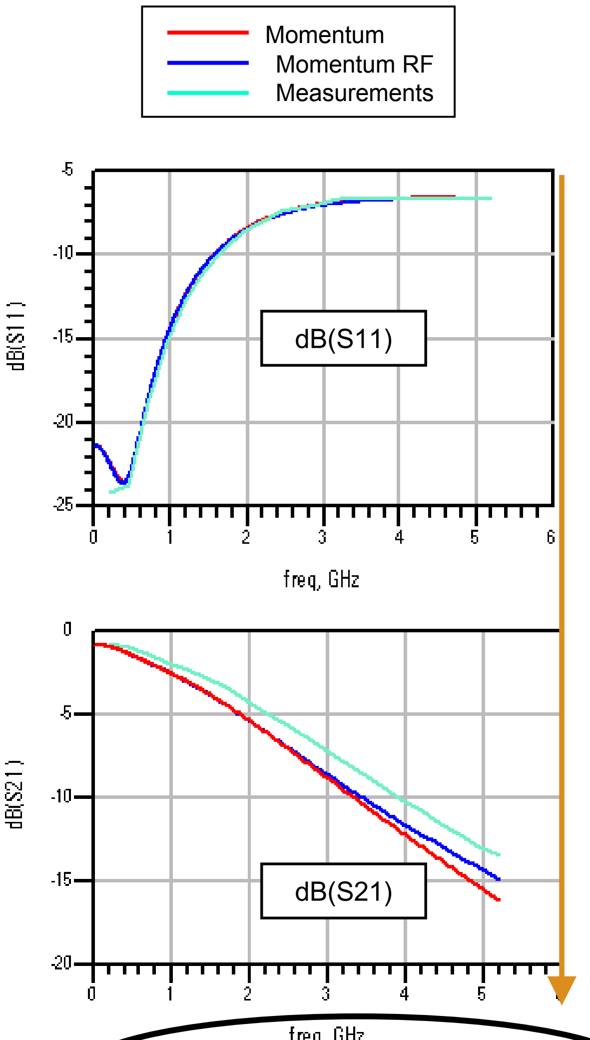
Matrix size	:	**56**
Process size	:	**7.59 MB**
User time	:	**45 s**

(*) **Example from National Semiconductor**

RFIC/MMIC Applications







Momentum

Mesh: 20 cells/wavelength, 5 GHz
Frequencies: 7

Matrix size	:	**274**
Process size	:	**10.29 MB**
User time	:	**11m 09s**

Momentum RF

Mesh: 20 cells/wavelength, 5 GHz
Frequencies: 7

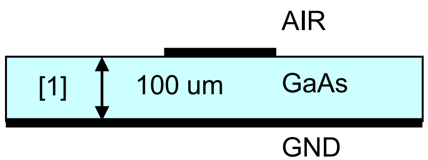
Matrix size	:	**35**
Process size	:	**3.33 MB**
User time	:	**1m 39s**

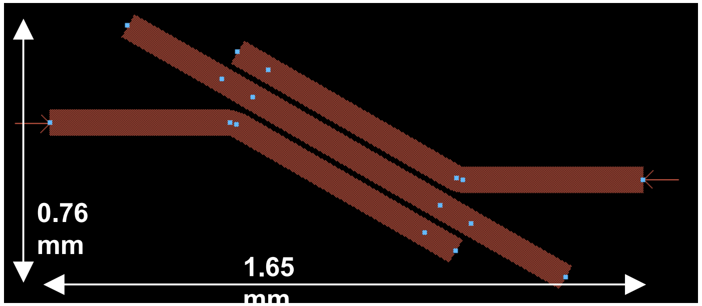
PC-NT Pentium II workstation (330 MHz)

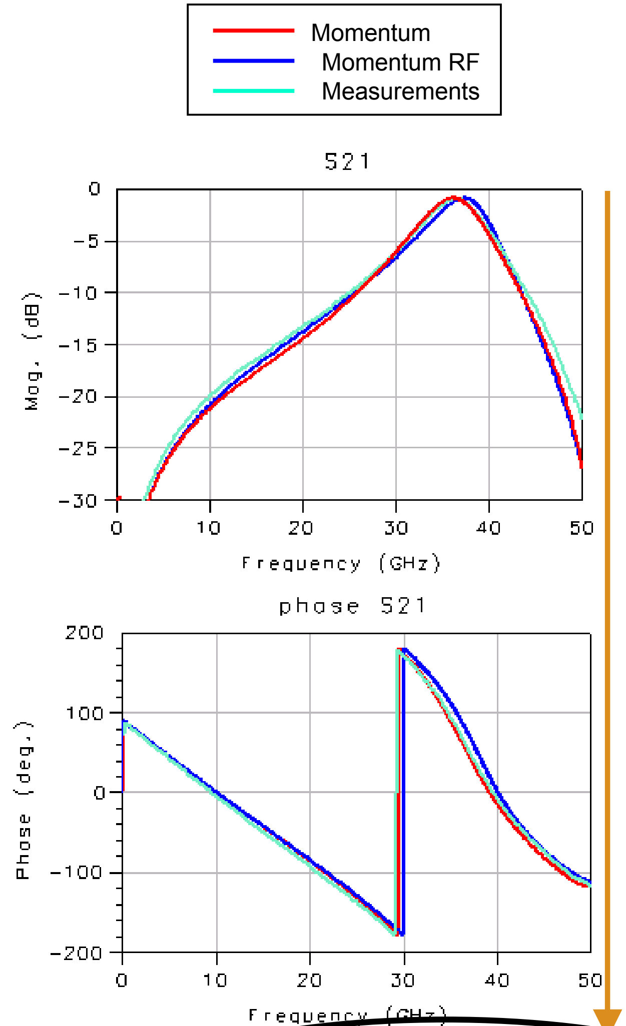
Rule of thumb: freq < 176 GHz

Agilent Technologies

RFIC / MMIC Applications







Momentum

Mesh: 20 cells/wavelength, 50 GHz
Frequencies: 12

Matrix size	:	**221**
Process size	:	**6.32 MB**
User time	:	**2 m 03 s**

Momentum RF

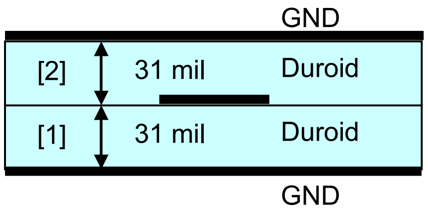
Mesh: 20 cells/wavelength, 50 GHz
Frequencies: 10

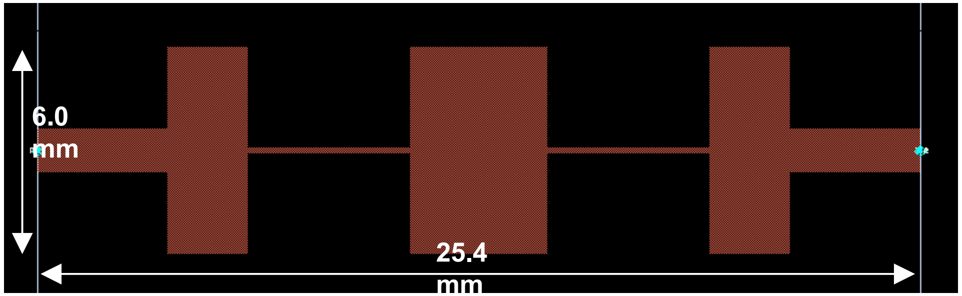
Matrix size	:	**203**
Process size	:	**4.50 MB**
User time	:	**0 m 26 s**

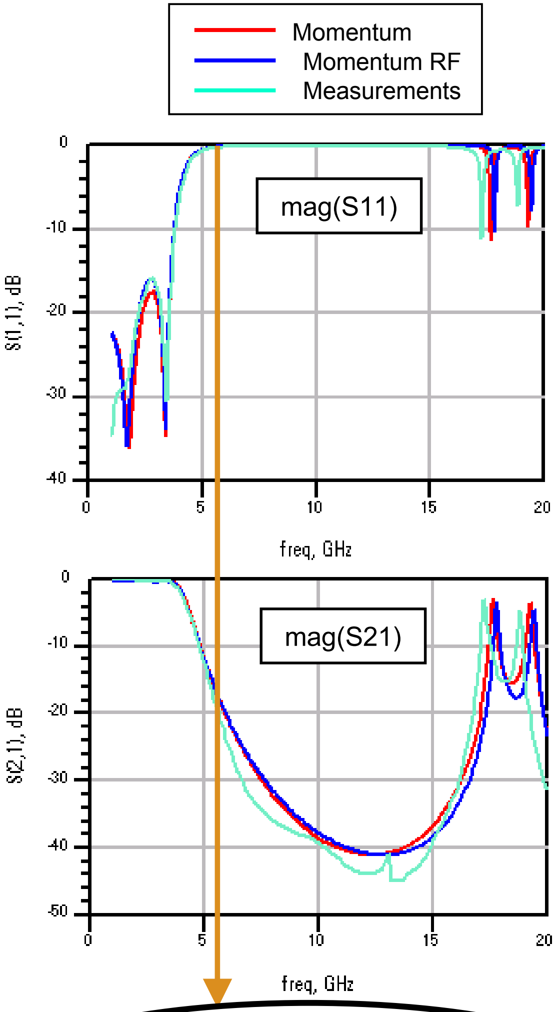
PC-NT Pentium II workstation (330 MHz)

Rule of thumb: freq < 83.3 GHz

Microwave Lowpass Filter (Stripline)







Momentum		
Mesh: 20 cells/wavelength, 15 GHz		
Frequencies: 20		
Process size	:	**18.07 MB**
User time	:	**36 m 07 s**

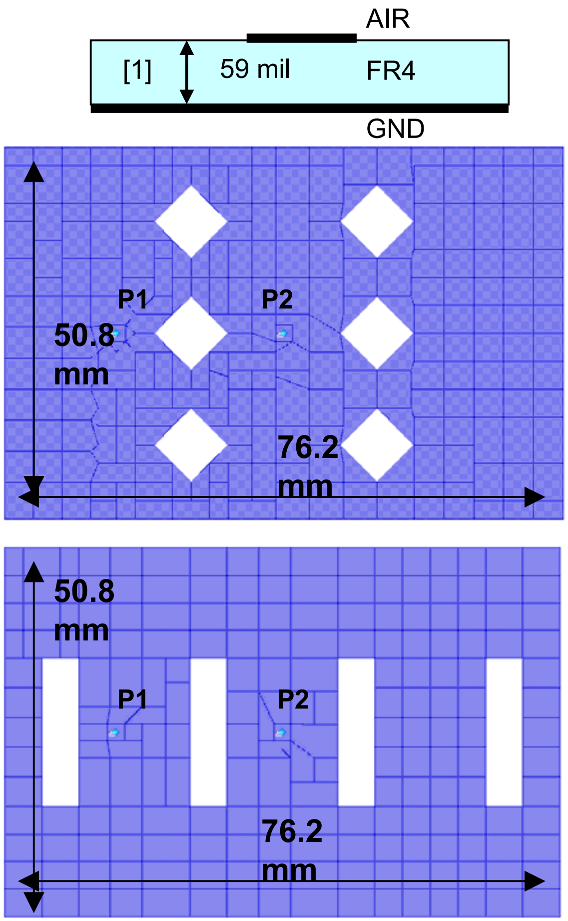
Momentum RF		
Mesh: 20 cells/wavelength, 15 GHz		
Frequencies: 15		
Process size	:	**12.29 MB**
User time	:	**2 m 21 s**

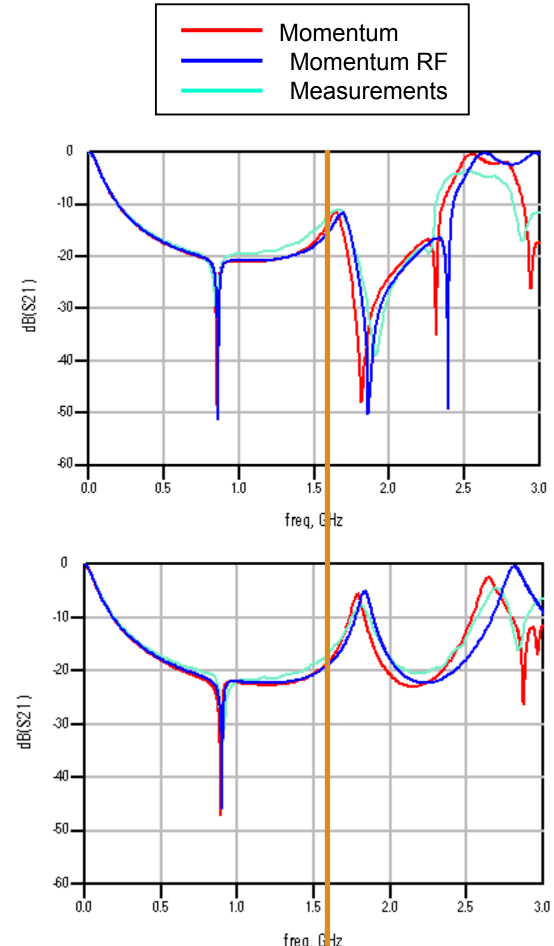
PC-NT Pentium II workstation (330 MHz)

Rule of thumb: freq < 5.76 GHz

Agilent Technologies

RF Board Power/Ground





Rule of thumb: freq < 1.63 GHz

Momentum

Process size : **20.8 MB**
User time : **30 m 42 s**

Momentum RF

Process size : **15.0 MB**
User time : **4 m 41 s**

Momentum

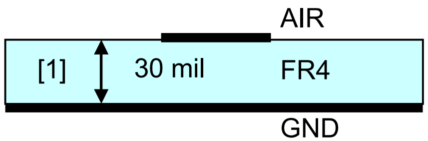
Process size : **20.2 MB**
User time : **50 m 29 s**

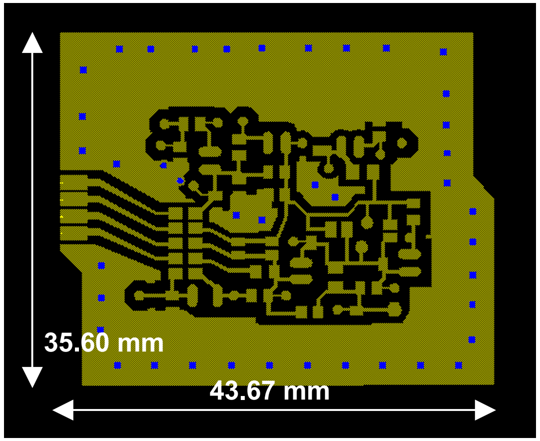
Momentum RF

Process size : **17.0 MB**
User time : **5 m 33 s**

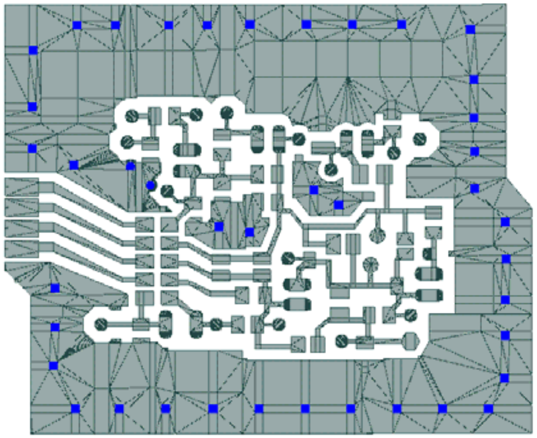
PC-NT Pentium II workstation (330 MHz)

RF Board Application





rectangular & triangular mesh

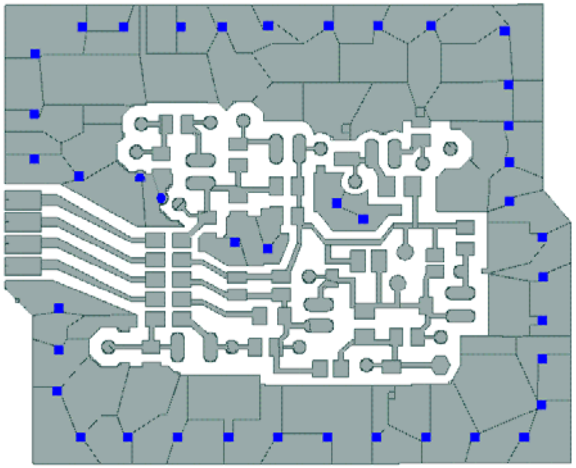


Momentum

Mesh: 20 cells/wavelength, 1 GHz
Ports: 60
Frequencies: 6

Matrix size	:	**3428**
Process size	:	**152.48 MB**
User time	:	**11h 04m 51s**

reduced polygonal mesh



Momentum RF

Mesh: 20 cells/wavelength, 1 GHz
Ports: 60
Frequencies: 6

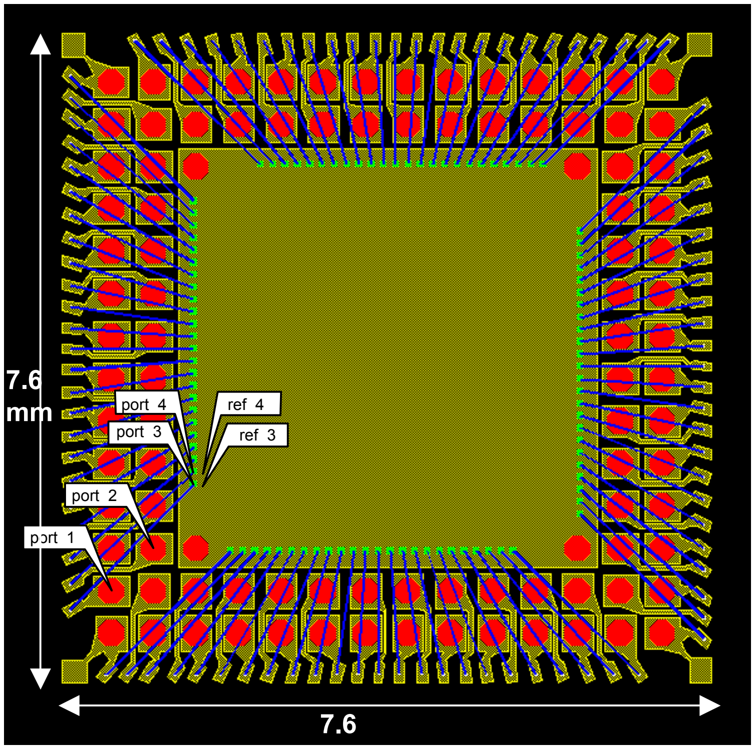
Matrix size	:	**733**
Process size	:	**59.35 MB**
User time	:	**48m 24s**

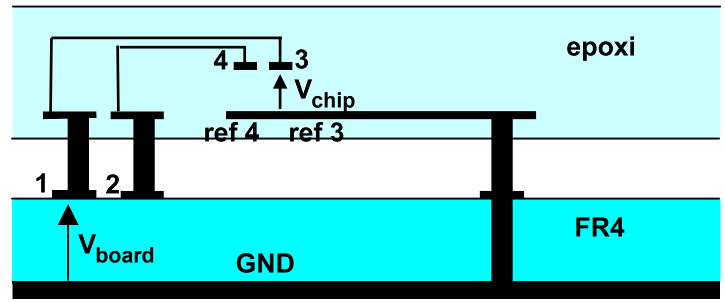
Speed & Capacity

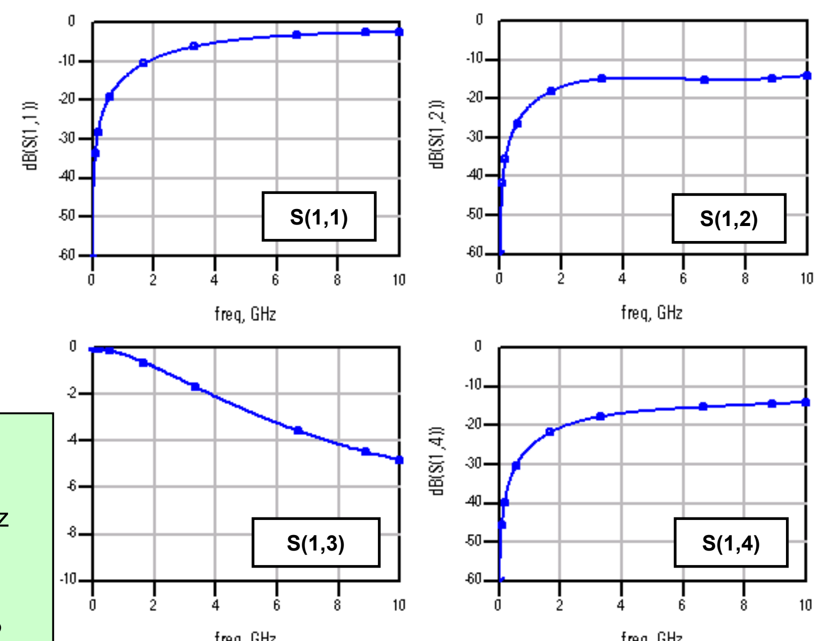
memory: 3 x
speed: 14 x

PC-NT Pentium II workstation (330 MHz)

Packaging Application







Momentum

Mesh: 20 cells/wavelength, 5 GHz

Matrix size : **8244**
Process size : **> 1 GB**
User time : **> 2 days**

Momentum RF

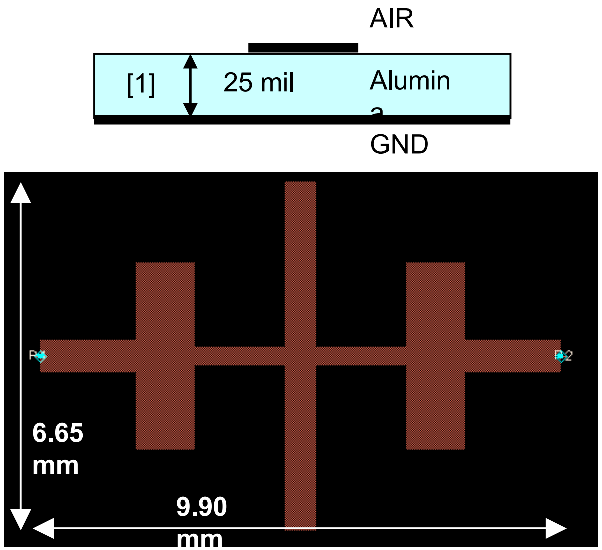
Mesh: 20 cells/wavelength, 5 GHz

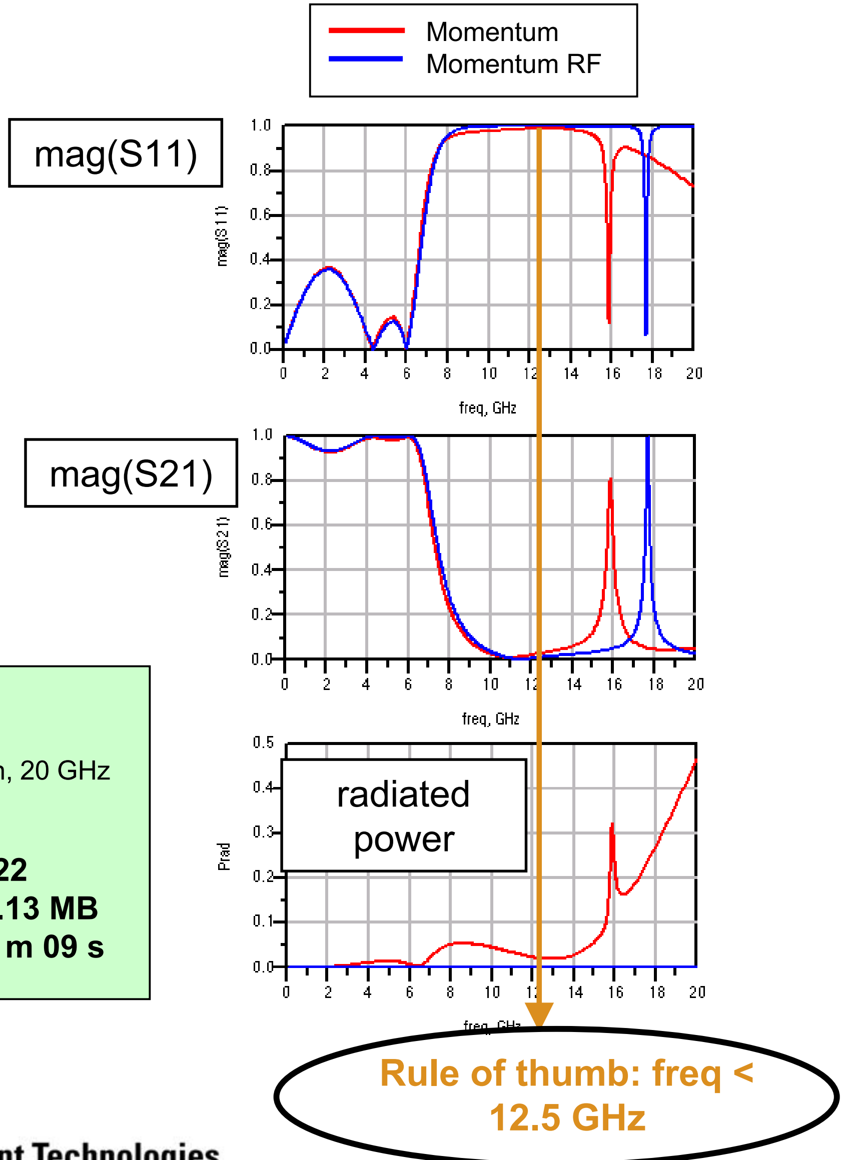
Matrix size : **1354**
Process size : **106.57 MB**
User time : **5h 17m 53s**

PC-NT Pentium II workstation (330 MHz)

Rule of thumb: freq < 13.8 GHz

Microwave Applications





Momentum

Mesh: 10 cells/wavelength, 20 GHz
Frequencies: 18

Matrix size	:	**181**
Process size	:	**2.92 MB**
User time	:	**1 m 02 s**

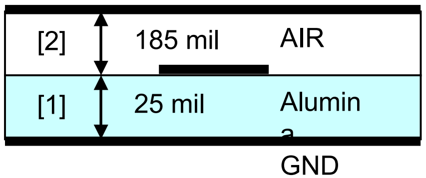
Momentum RF

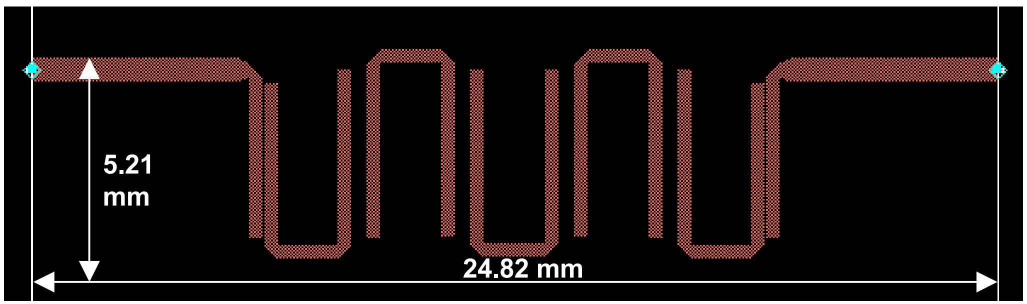
Mesh: 10 cells/wavelength, 20 GHz
Frequencies: 14

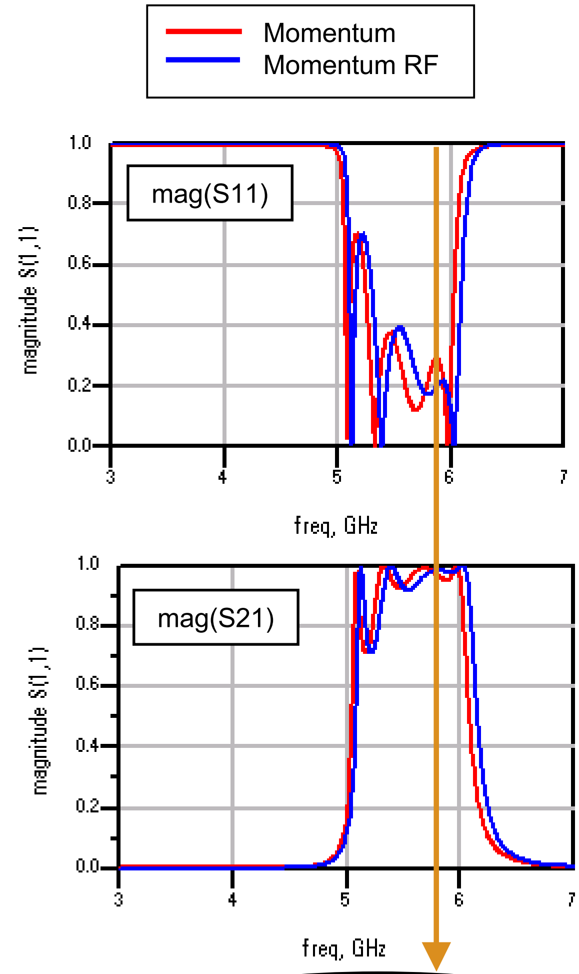
Matrix size	:	**122**
Process size	:	**2.13 MB**
User time	:	**0 m 09 s**

PC-NT Pentium II workstation (330 MHz)

Microwave Applications







Rule of thumb: freq < 5.9 GHz

Momentum

Mesh: 20 cells/wavelength, 7 GHz
Frequencies: 27

Process size	:	**8.26 MB**
User time	:	**7 m 53 s**

Momentum RF

Mesh: 20 cells/wavelength, 7 GHz
Frequencies: 25

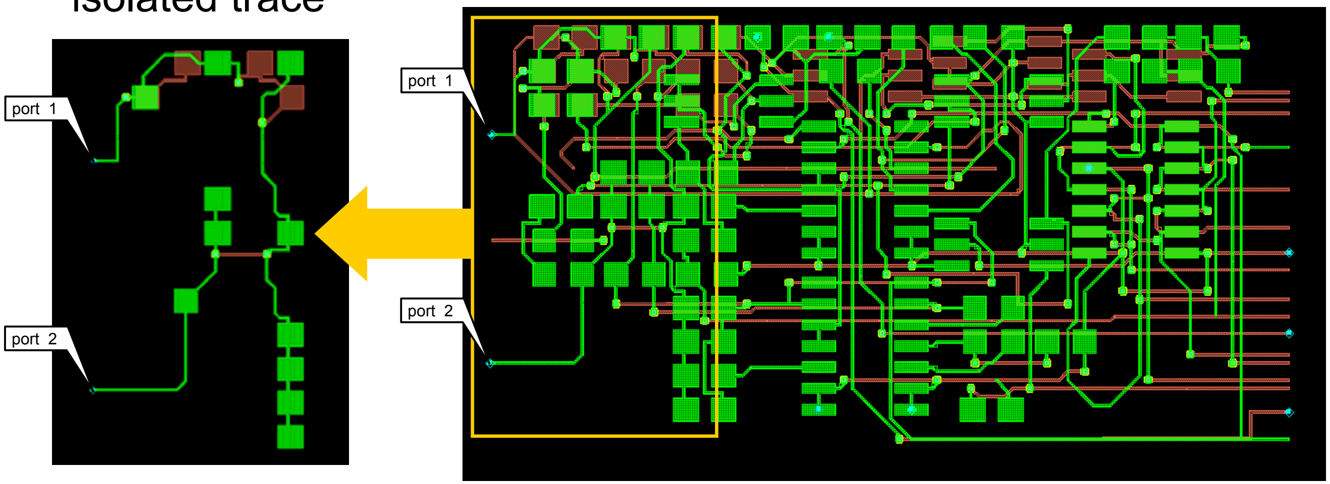
Process size	:	**4.75 MB**
User time	:	**0 m 29 s**

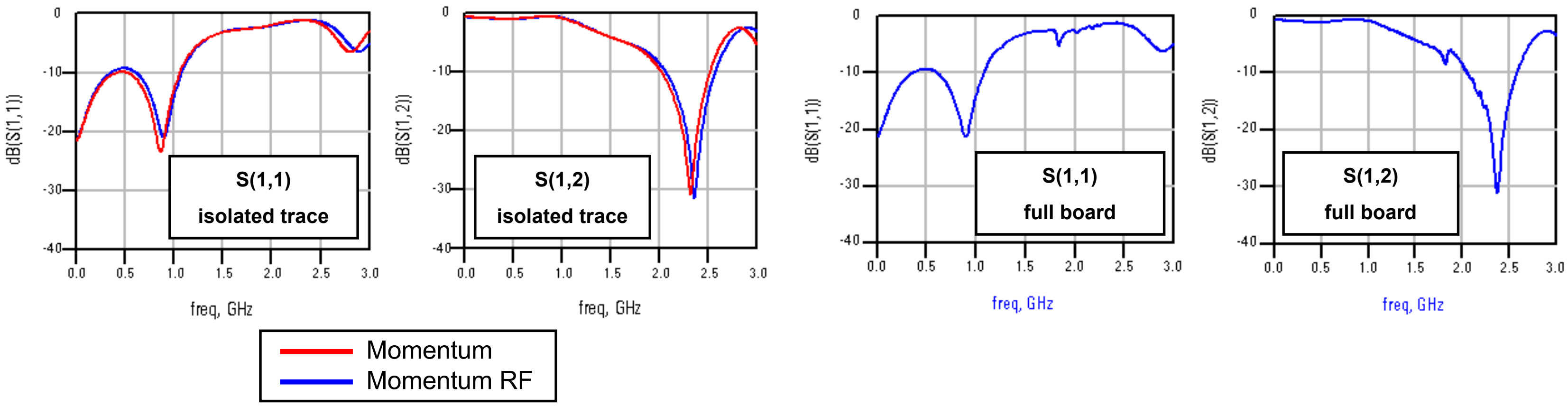
PC-NT Pentium II workstation (330 MHz)

Digital Application

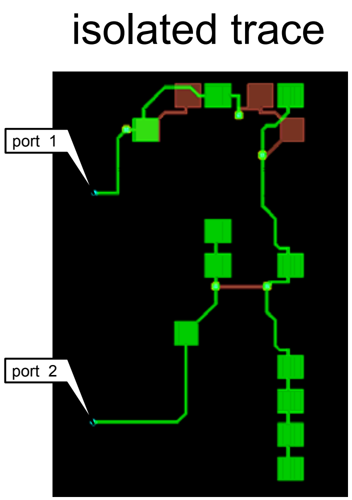
isolated trace

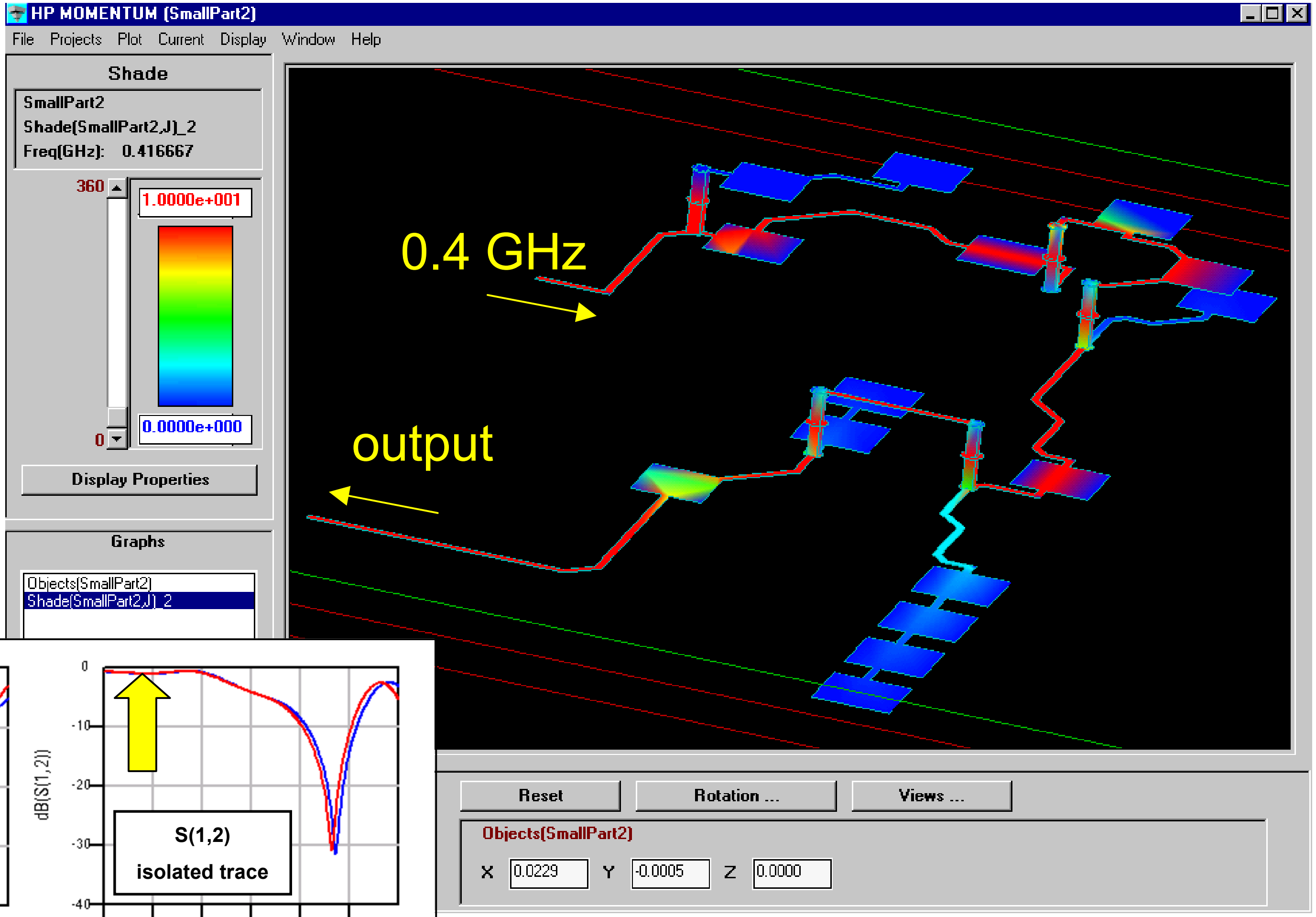
full board

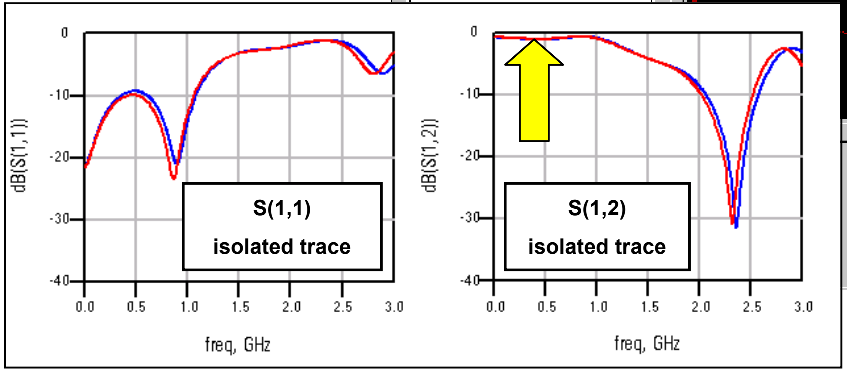




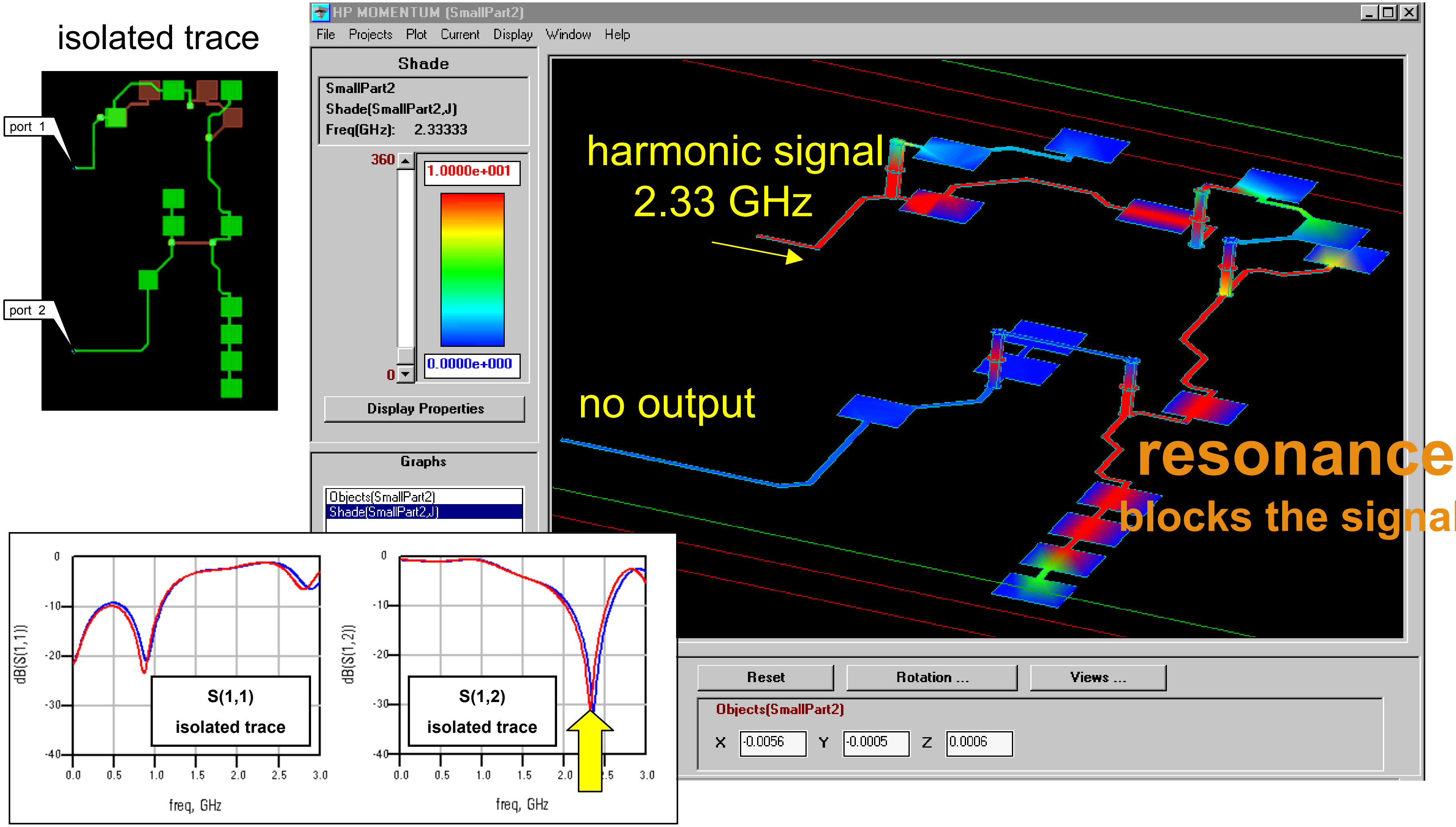
Digital Application



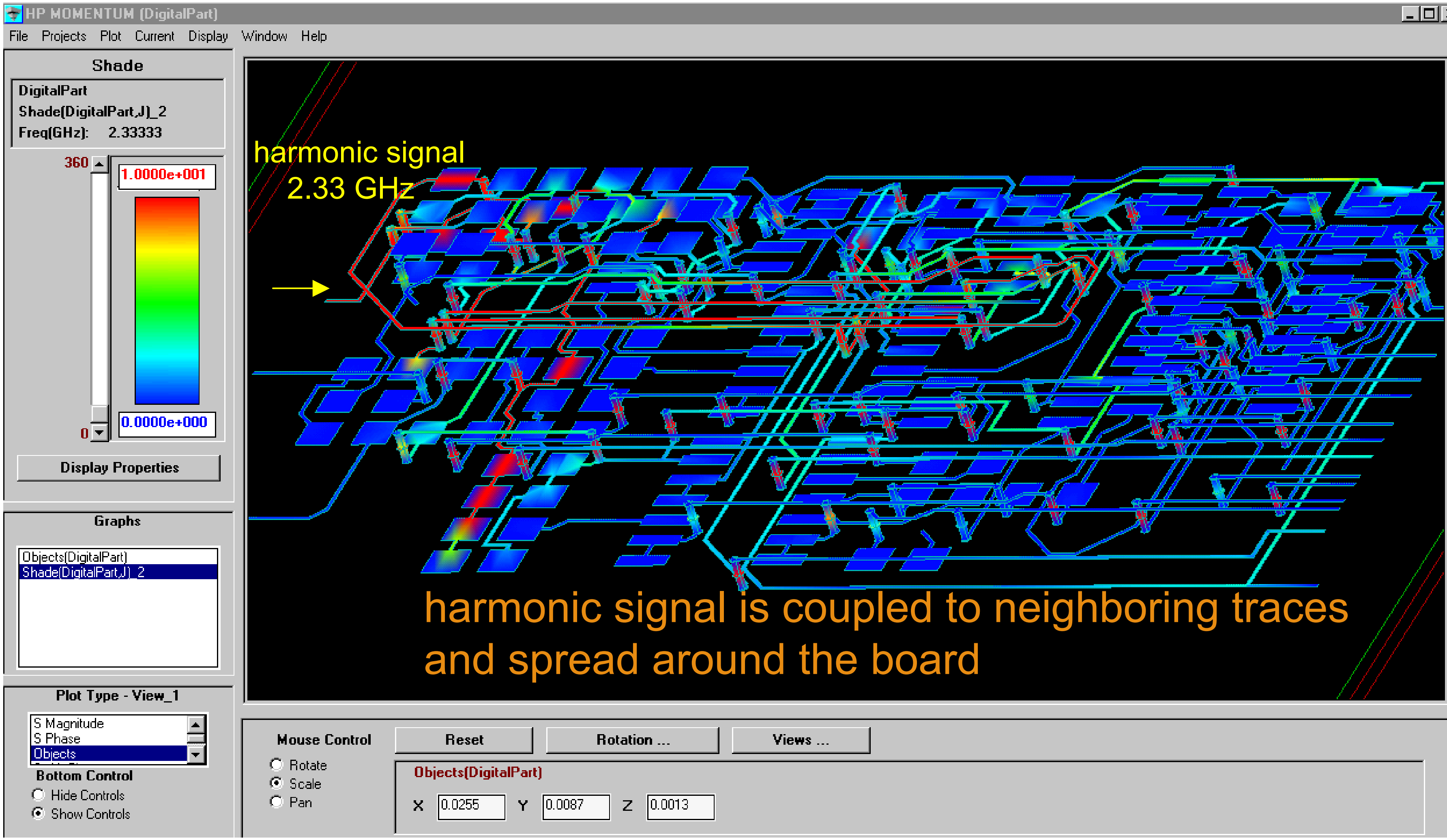




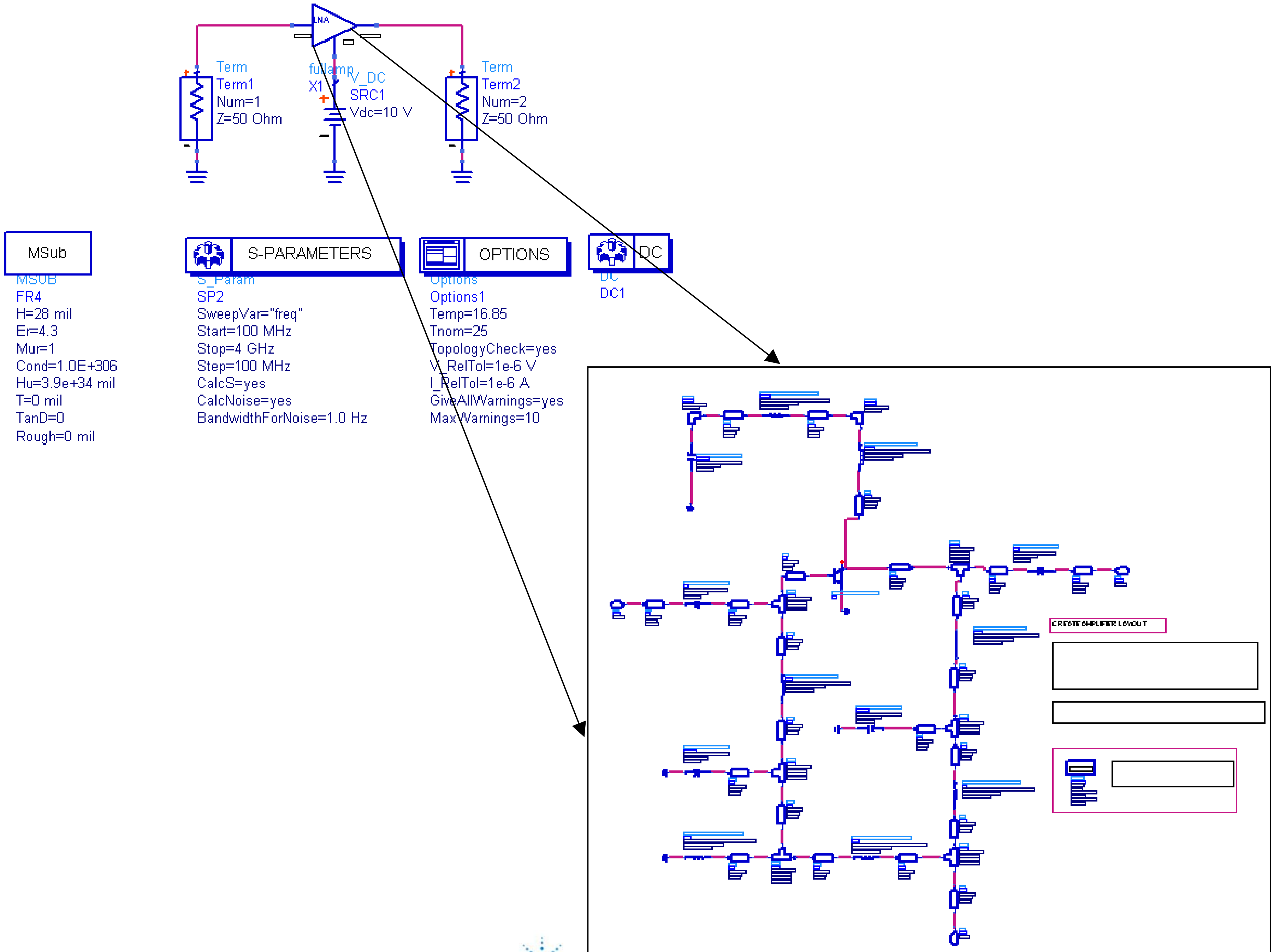
Digital Application

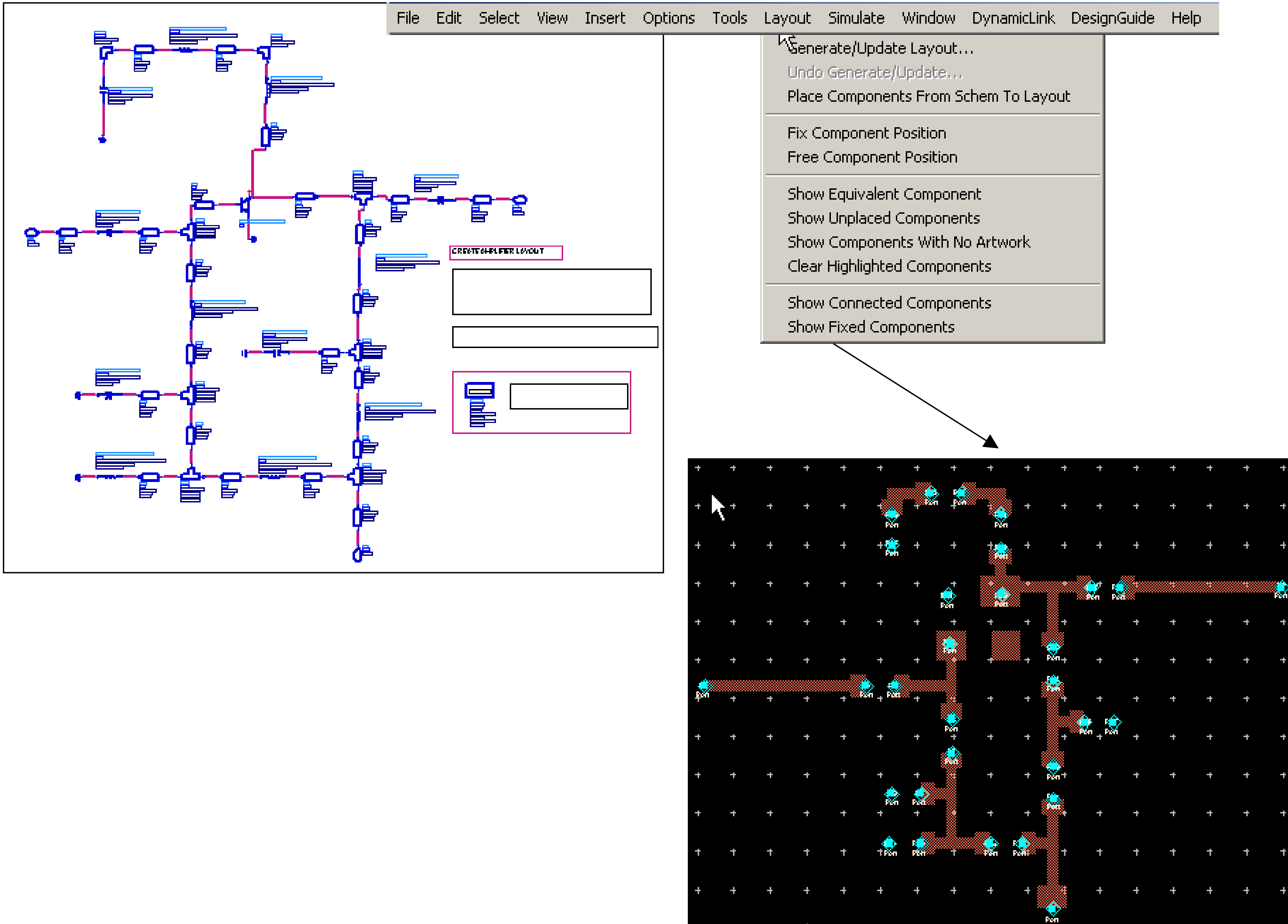


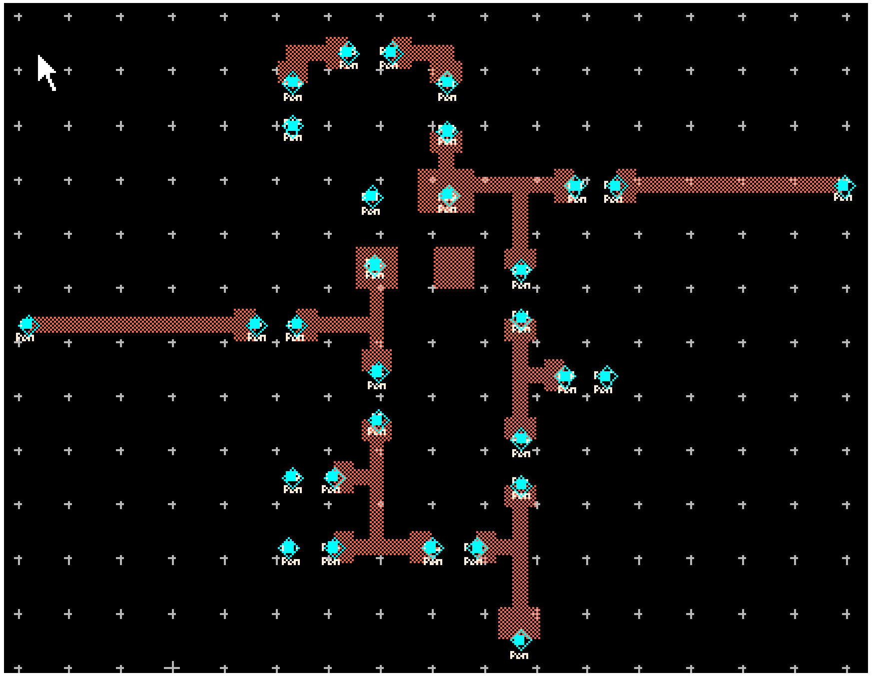
Digital Application



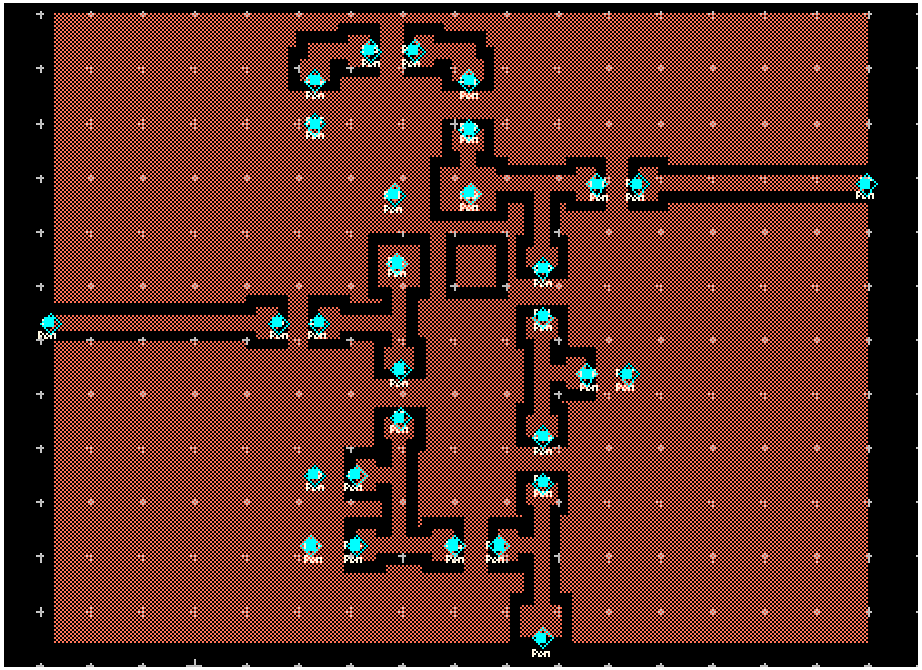
LNA EXAMPLE


LNA
Term
Term1
Num=1
Z=50 Ohm
fullamp
X1
V_DC
SRC1
Vdc=10 V
Term
Term2
Num=2
Z=50 Ohm
MSub
MSUB
FR4
H=28 mil
Er=4.3
Mur=1
Cond=1.0E+306
Hu=3.9e+34 mil
T=0 mil
TanD=0
Rough=0 mil
S-PARAMETERS
S_Param
SP2
SweepVar="freq"
Start=100 MHz
Stop=4 GHz
Step=100 MHz
CalcS=yes
CalcNoise=yes
BandwidthForNoise=1.0 Hz
OPTIONS
Options
Options1
Temp=16.85
Tnom=25
TopologyCheck=yes
V_RelTol=1e-6 V
I_RelTol=1e-6 A
GiveAllWarnings=yes
MaxWarnings=10
DC
DC
DC1


File Edit Select View Insert Options Tools Layout Simulate Window DynamicLink DesignGuide Help
Generate/Update Layout...
Undo Generate/Update...
Place Components From Schem To Layout
Fix Component Position
Free Component Position
Show Equivalent Component
Show Unplaced Components
Show Components With No Artwork
Clear Highlighted Components
Show Connected Components
Show Fixed Components



Create a ground plane



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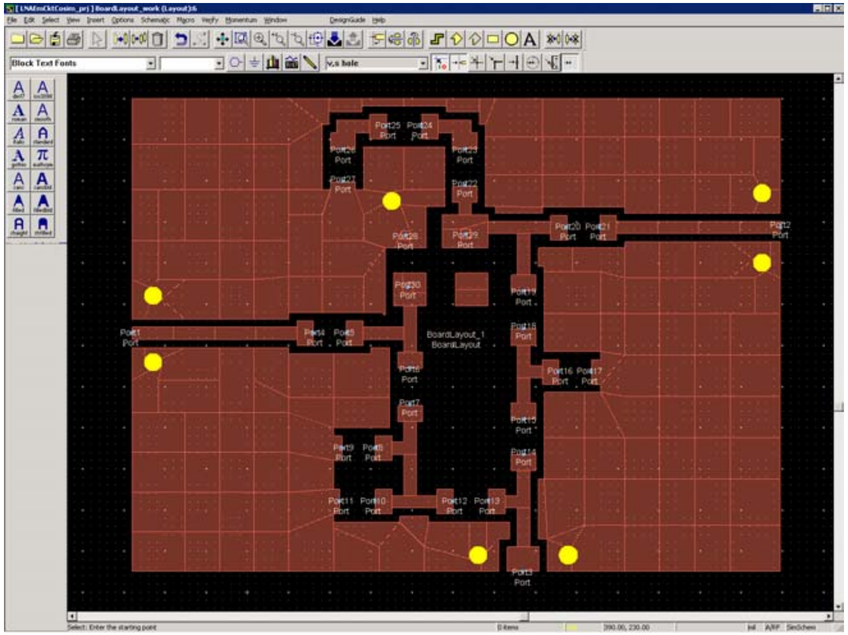
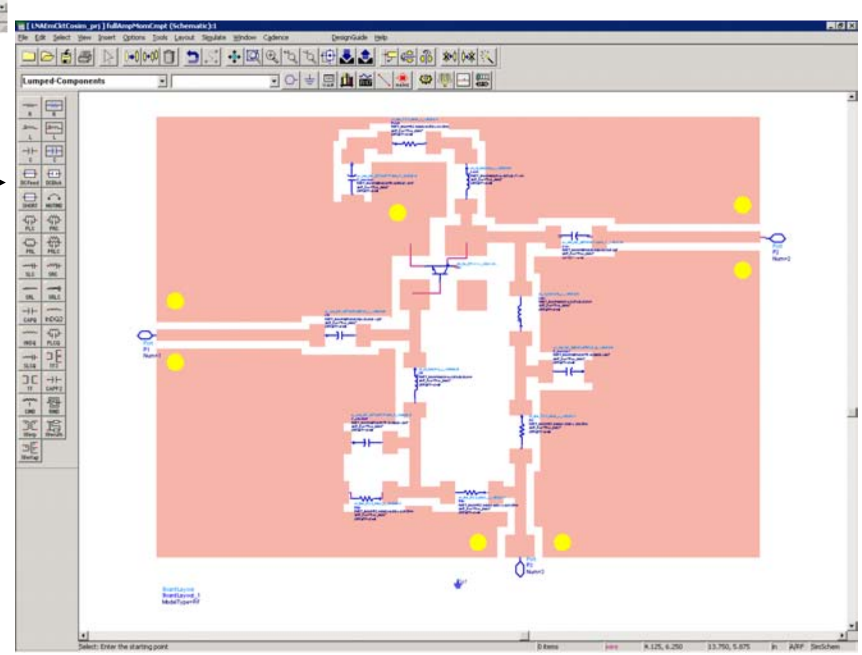


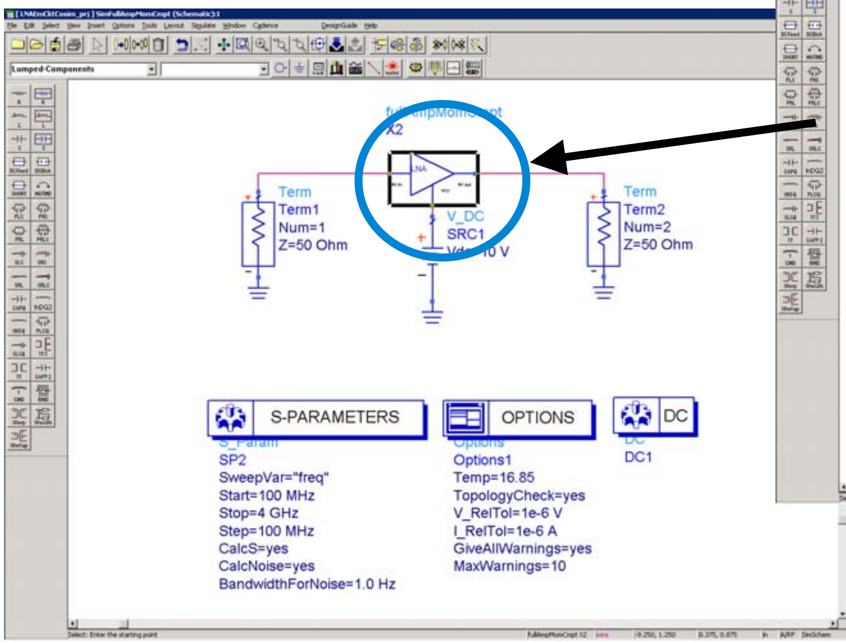


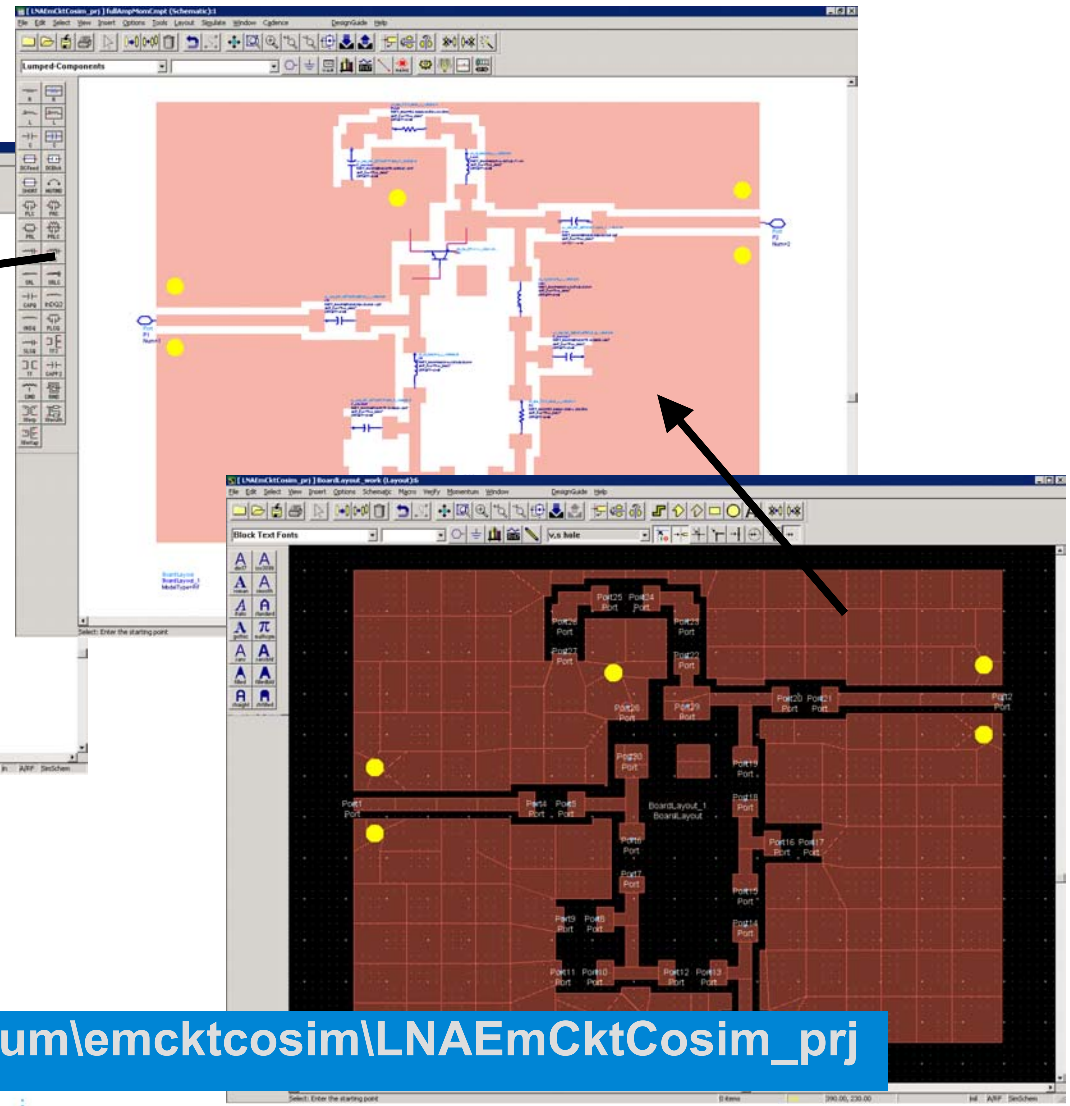
Create a Layout component
And
Place it in the Schematic
And
Reconnect the lumped components

Momentum Component (EM/circuit co-simulation)

Example included in ADS 2002 & higher

- **EM/Circuit co-simulation from the schematic environment**

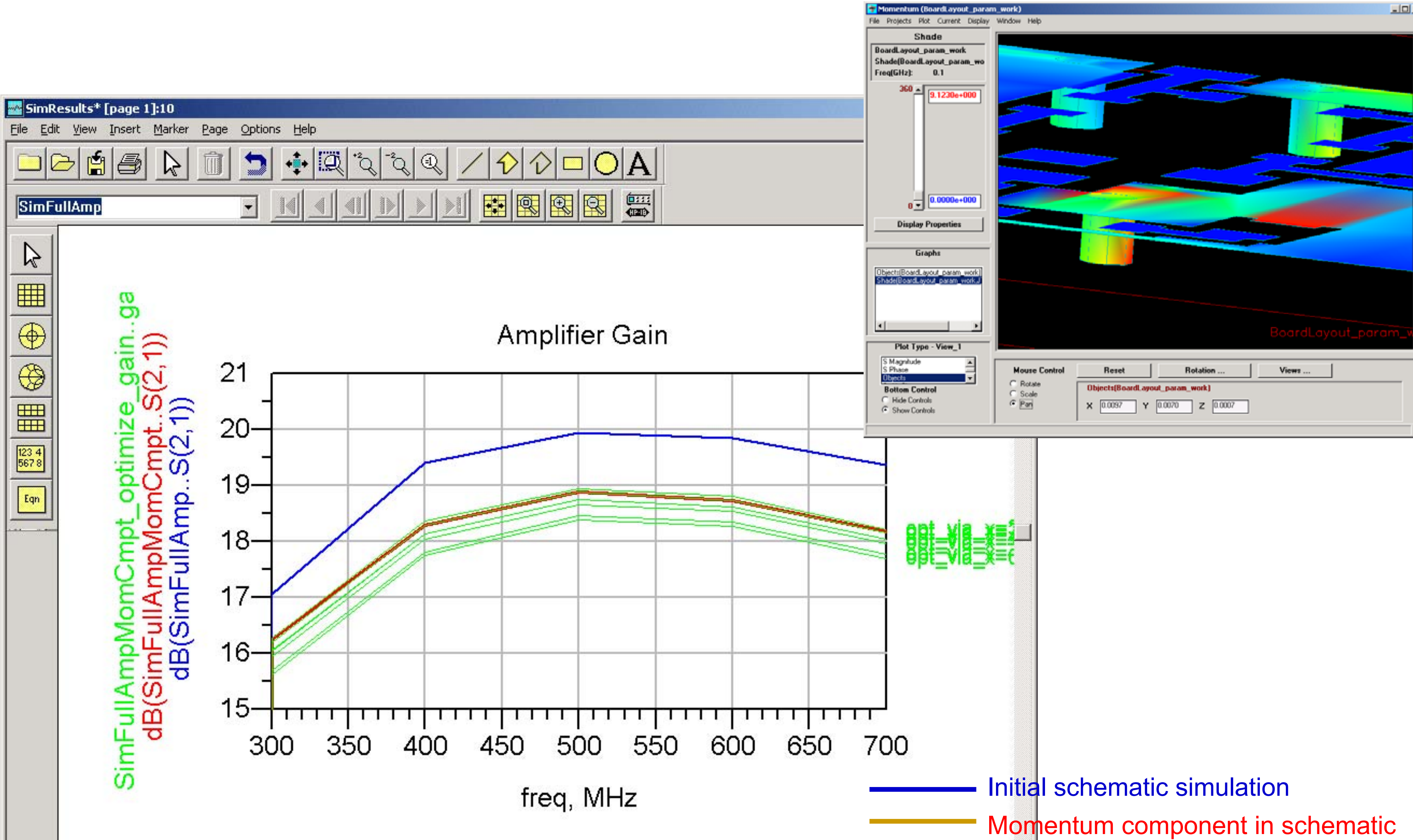




C:\ADS2002\Examples\Momentum\emcktcosim\LNAEmCktCosim_prj

Momentum Component (EM/circuit co-simulation)

Example included in ADS 2002 & higher (slightly modified)



Initial schematic simulation

Momentum component in schematic

Momentum component in schematic with swept variable for via location

Modified version provided: (LNAEmCktCosim_prj.zap)

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Wrap-up: *Q & A*

Questions?