SPIRAL™
3D Spiral Inductance Synthesis and Design Tool

OEA International, Inc.

155 East Main Ave, Suite 110

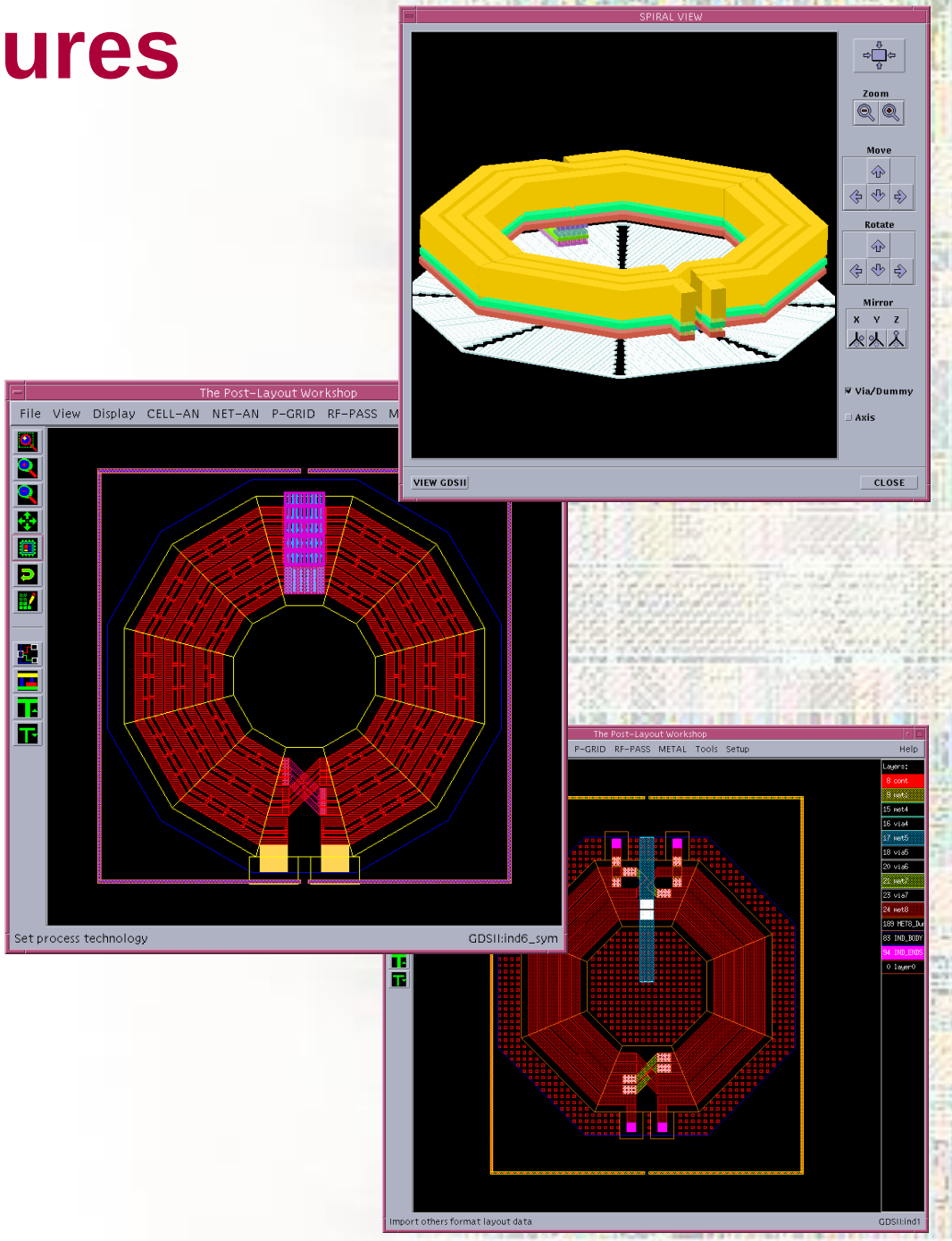
Morgan Hill, CA 95037

www.oea.com

OEA International, Inc.

SPIRAL Features

- Fully Automatic Synthesis of Spiral Inductors, Differential Inductors, Baluns, and Transformers
  - Full Physical DRC Clean Layout in GDSII or DF2 Format
  - Full Spice RCLK Output
  - Compact Model to Fit Narrow or Wide-Band Applications
  - S-, Y-, and Z-Parameter Models
  - Monte Carlo and EM Analysis
- Very High Accuracy & FAST
  - Matches Measured Silicon
  - Patterned Ground Shield Support
  - Substrate, Skin & Proximity Effect
- Ready for 90nm & 65nm Design
  - Dummy Metal Fill (for CMP)
  - Slotting to User DRC Rules
- Extremely Easy to Use
  - Targeted for RF Designer
  - Automatic Optimization for best Q at frequency and size
  - Automatic Design Space Exploration
- Multiple Use Models
  - Standalone Batch and Interactive Operation
  - Fully Integrated with Cadence

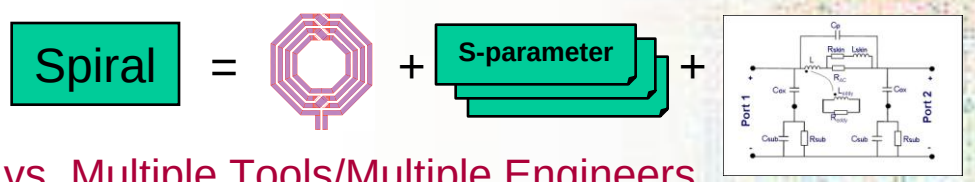


OEA International, Inc.

Spiral Value Proposition

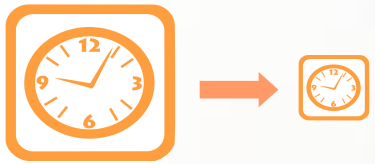
Significant Time/Effort-to-Model Reduction

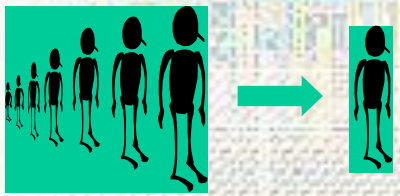
- Single Tool produces layout, S-, Y-, Z- Parameters, and Compact Spice Model



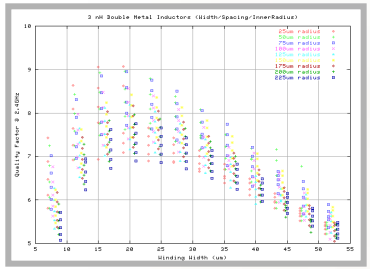
- Single Tool/Single Engineer vs. Multiple Tools/Multiple Engineers

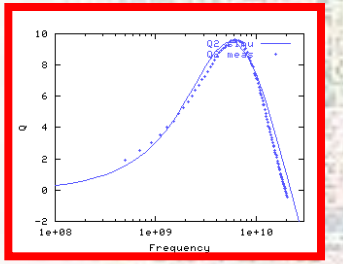
Very Fast Runtime - Minutes vs. Hours





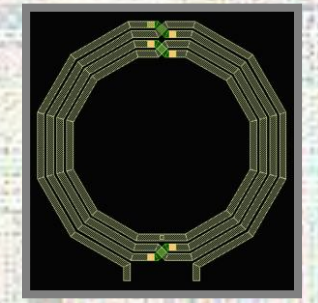
- Thorough Design Space Exploration
  - Ensures Optimum Device is Found





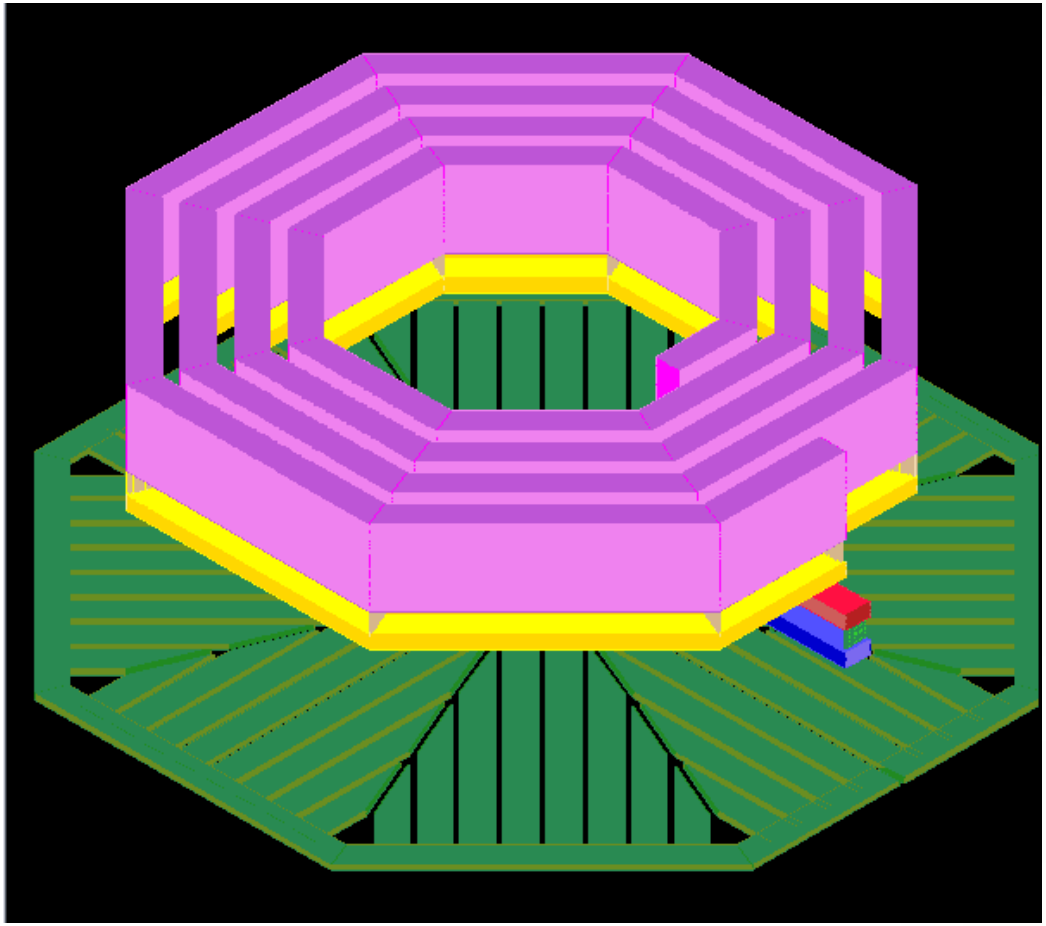
- High Accuracy – Simulations Match Measurements

- Make Alternative Spiral Types Readily Available
  - Provides significant performance and die size benefits



OEA International, Inc.

Standard Two Port Inductors

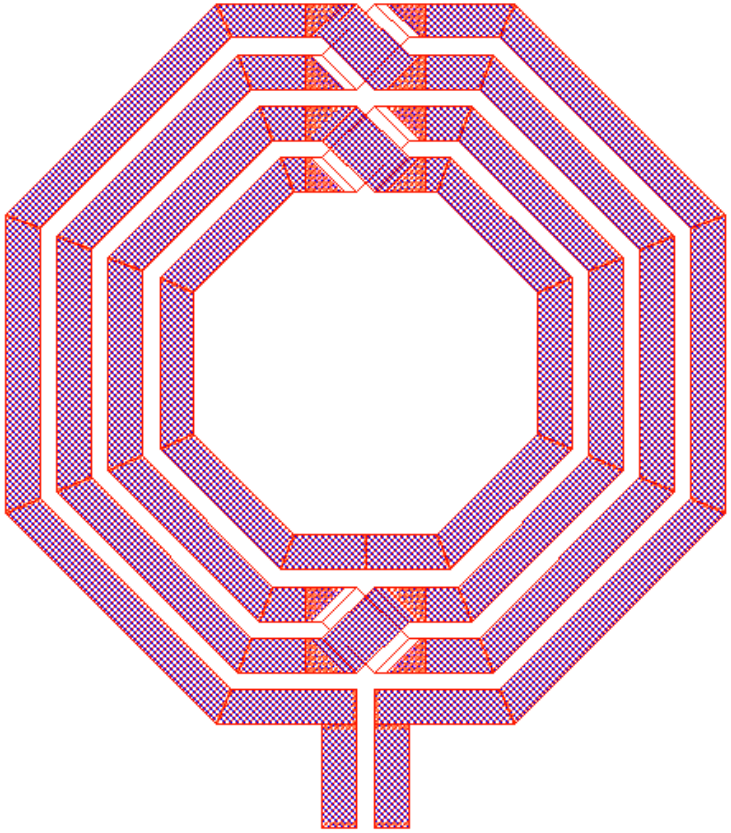


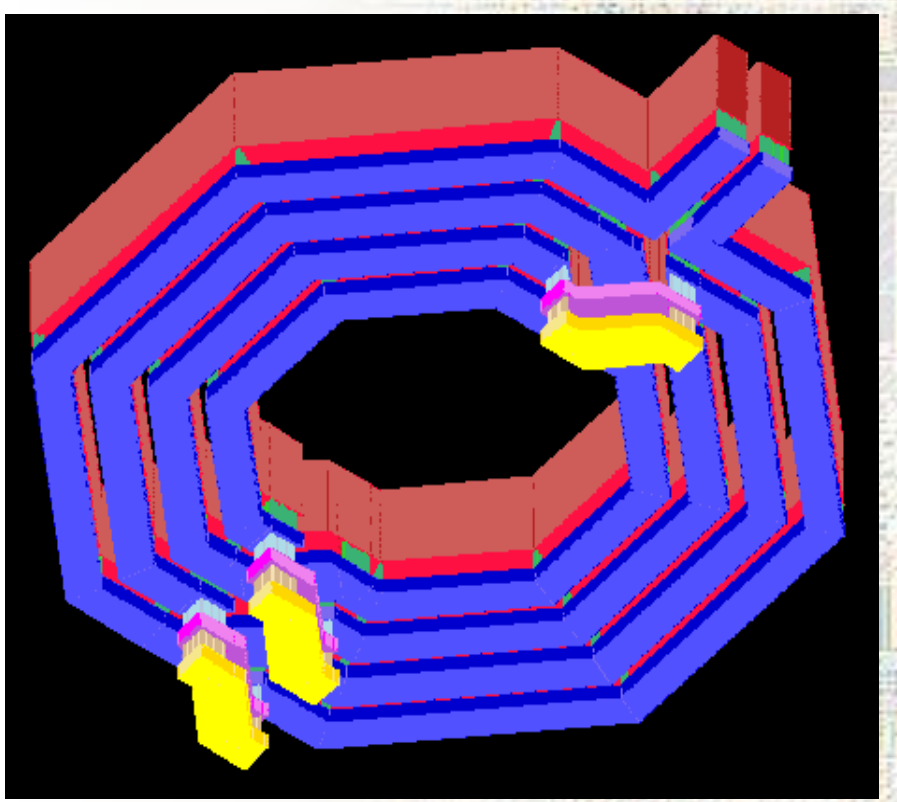
Optimization Requires Choosing:

- Metal layer(s)
- Radius
- Winding Width
- Bridge Width
- Spacing
- Etc…

OEA International, Inc.

Symmetric 3-Port Differential Inductors

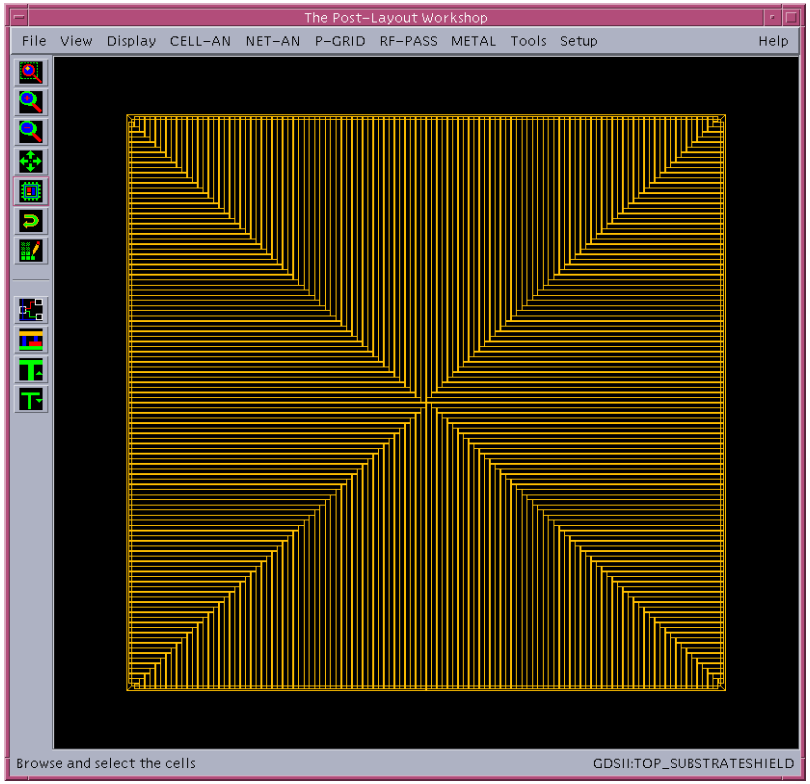


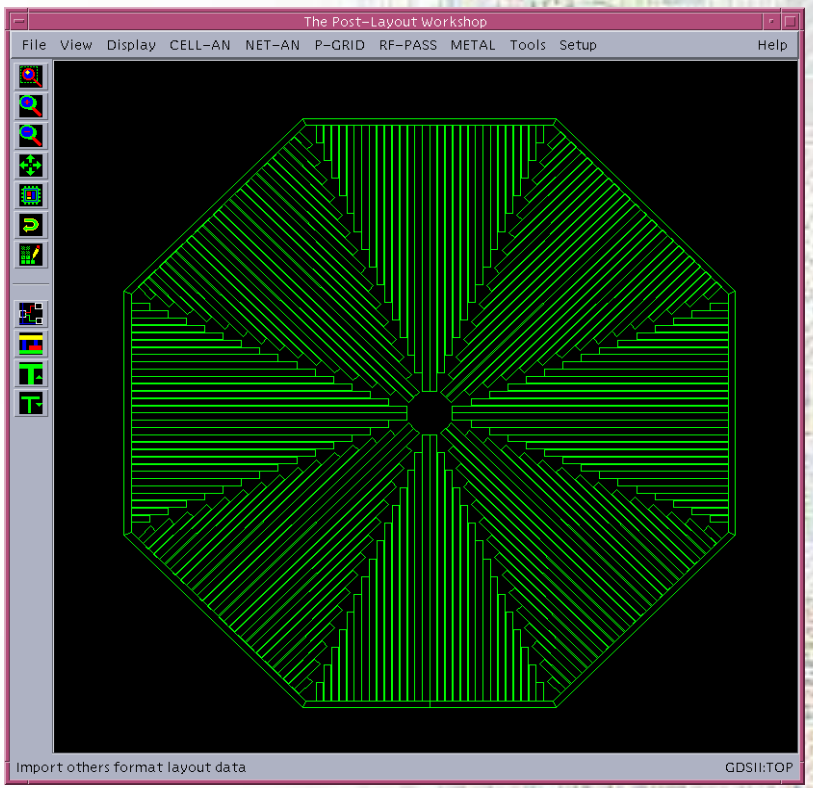


- **Symmetric Center Tapped Inductors instead of 2 ‘uncoupled’ inductors:**
  - **Easily defined center tap**
  - **Reduced chip area**
  - **Higher Q (reduced substrate losses)**
  - **No need to model parasitic coupling**

OEA International, Inc.

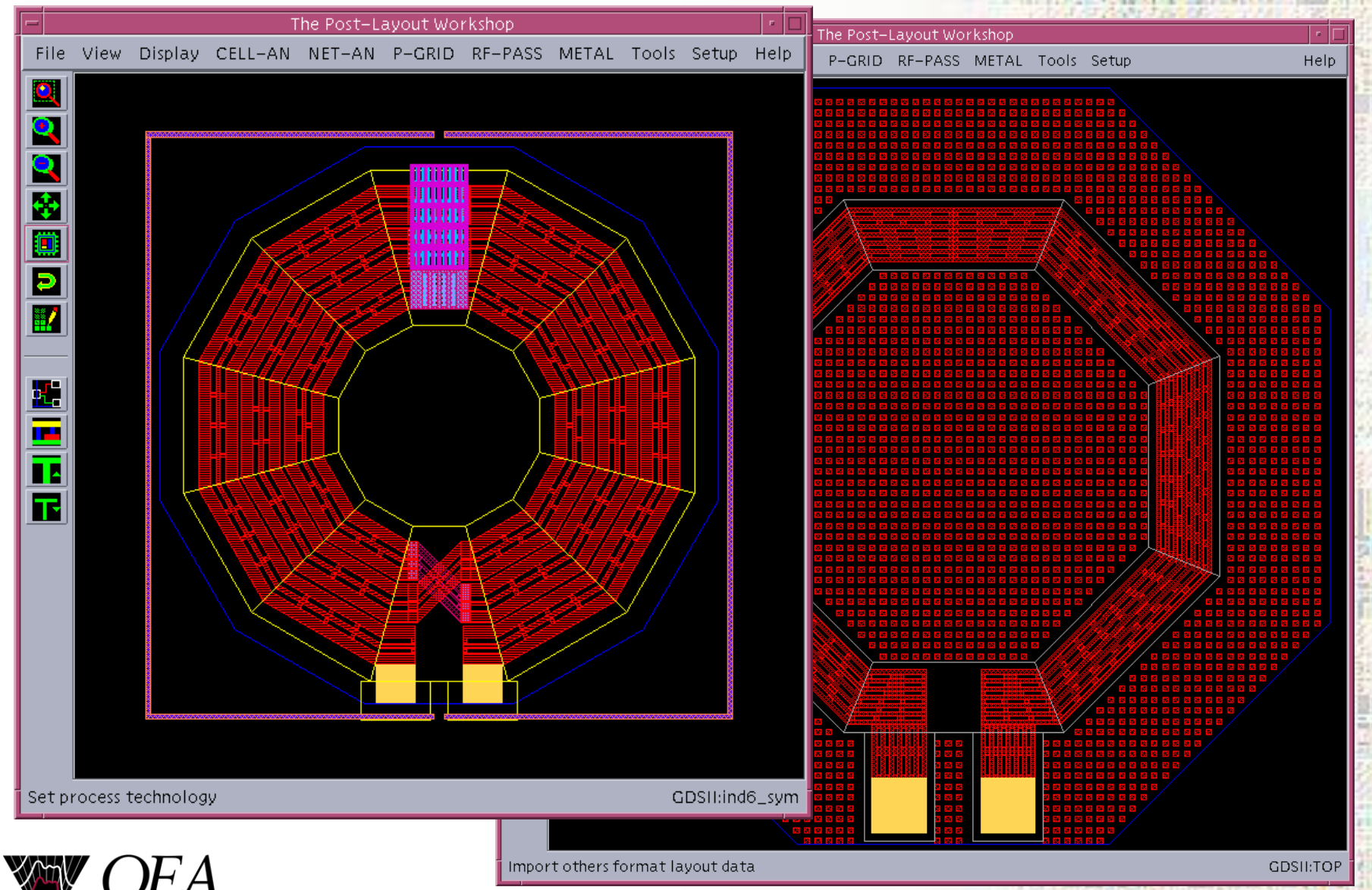
Patterned Ground Shields





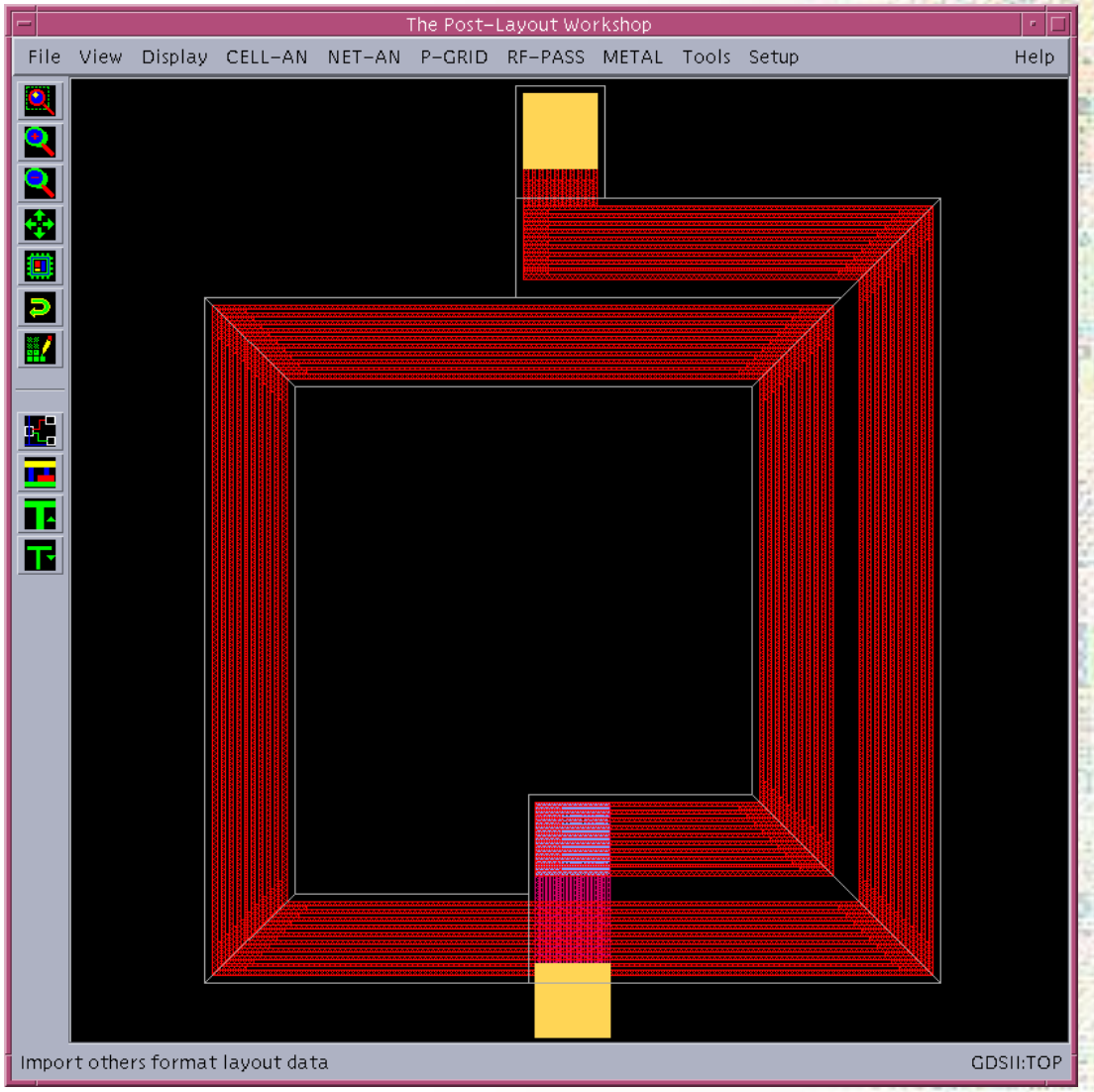
OEA International, Inc.

Slotted Spiral Inductors With or Without Dummy Metal Fill



OEA International, Inc.

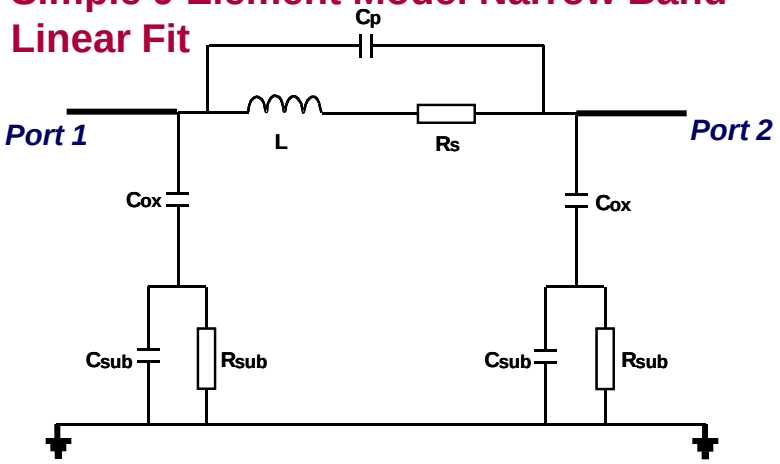
Striped Spiral Inductor with Connections at Corners



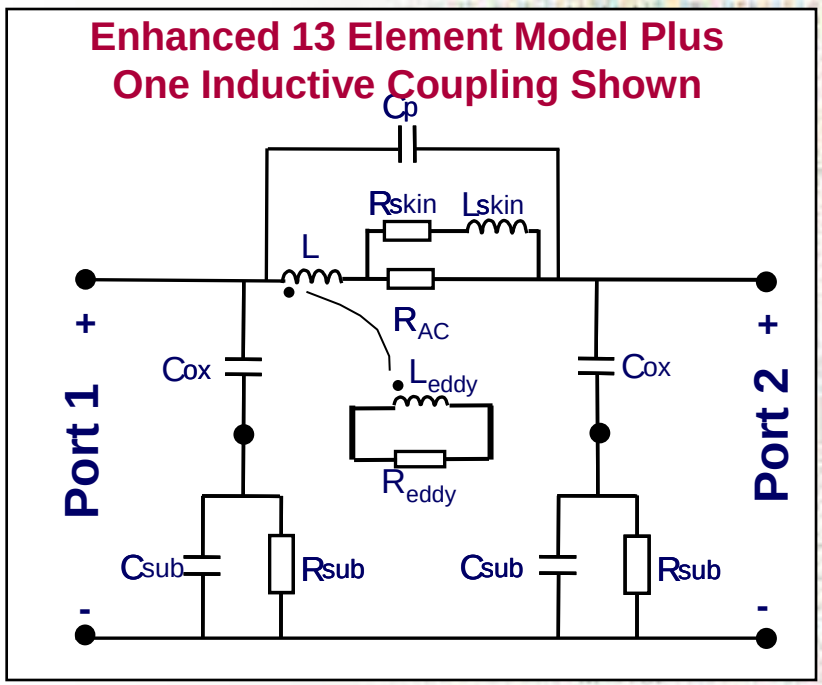
OEA International, Inc.

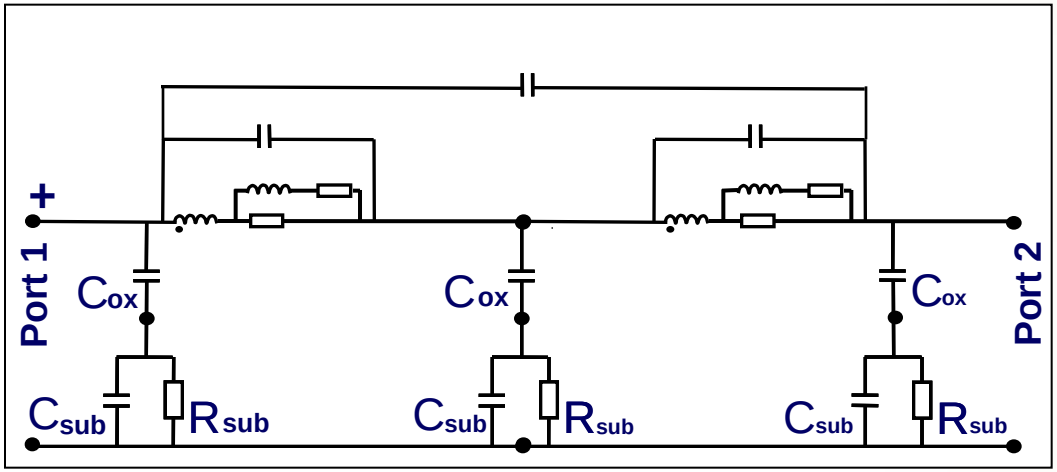
Compact Model Fitting

Simple 9 Element Model Narrow Band Linear Fit



Enhanced 13 Element Model Plus One Inductive Coupling Shown

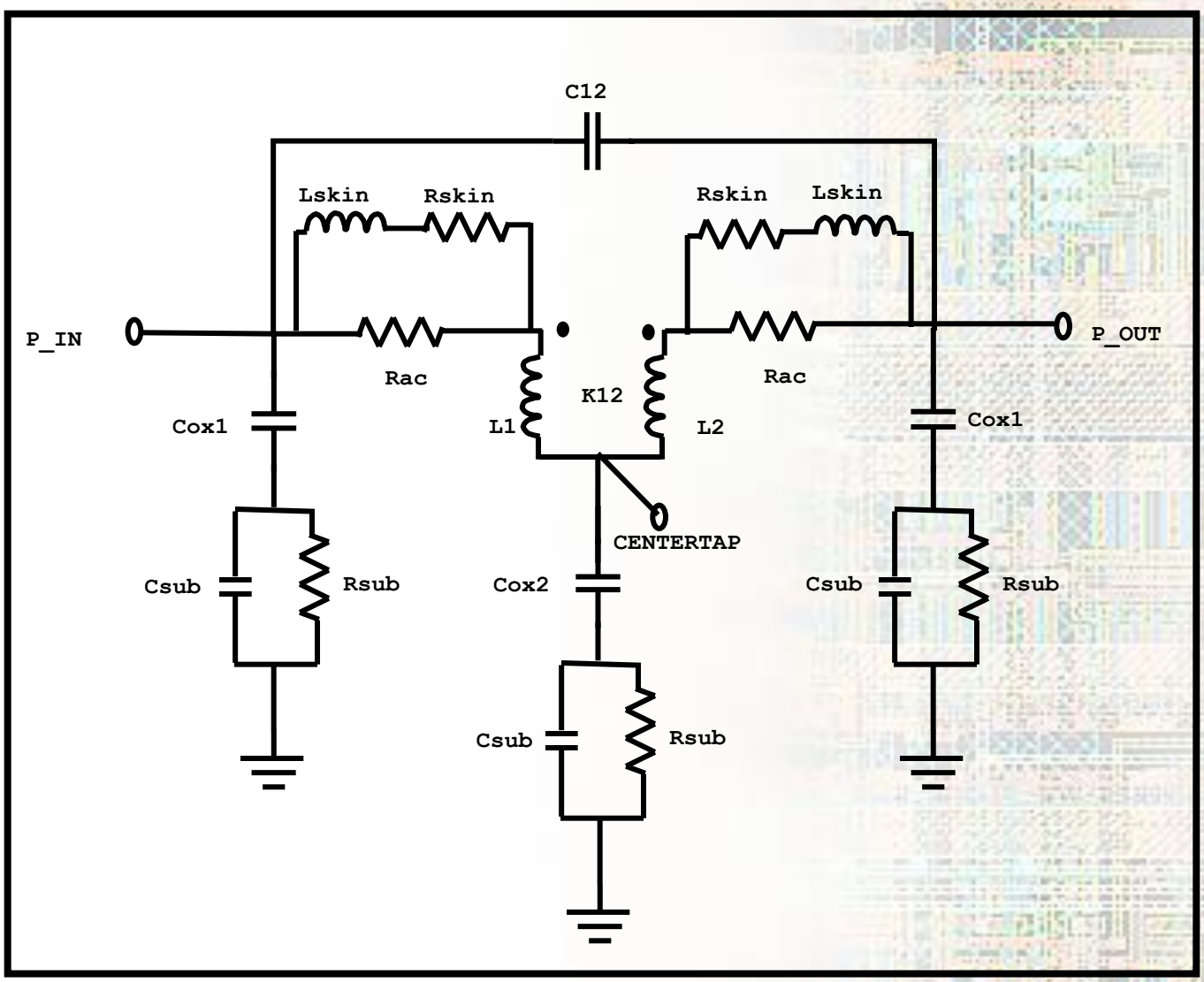




Berkeley / IBM 2Π Model (Mutual Inductances not Shown) Often Fits past Resonance

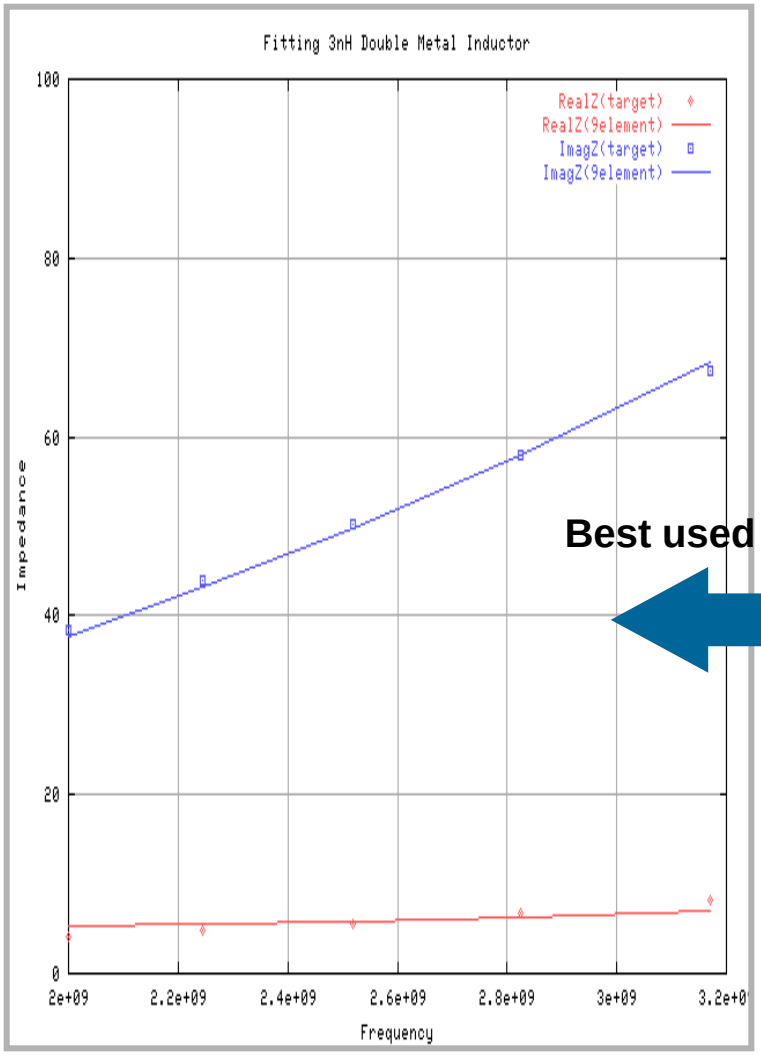
OEA International, Inc.

Symmetric Inductor Lumped Model

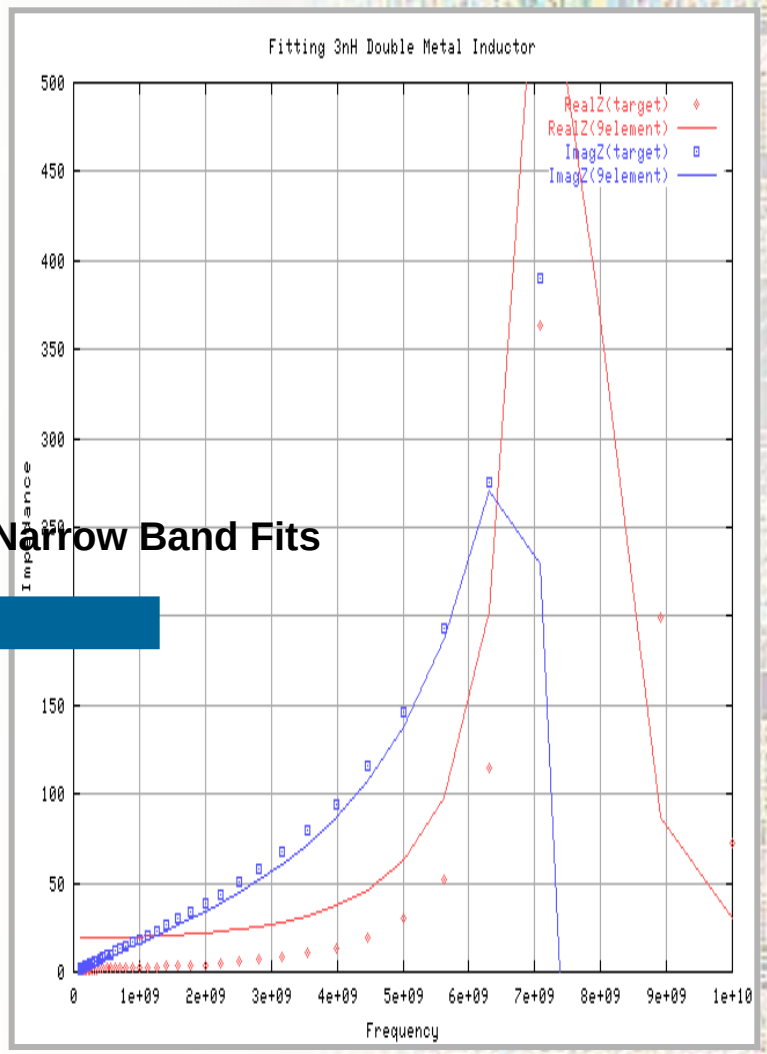


OEA International, Inc.

9 Element Model Fit



Best used for Narrow Band Fits

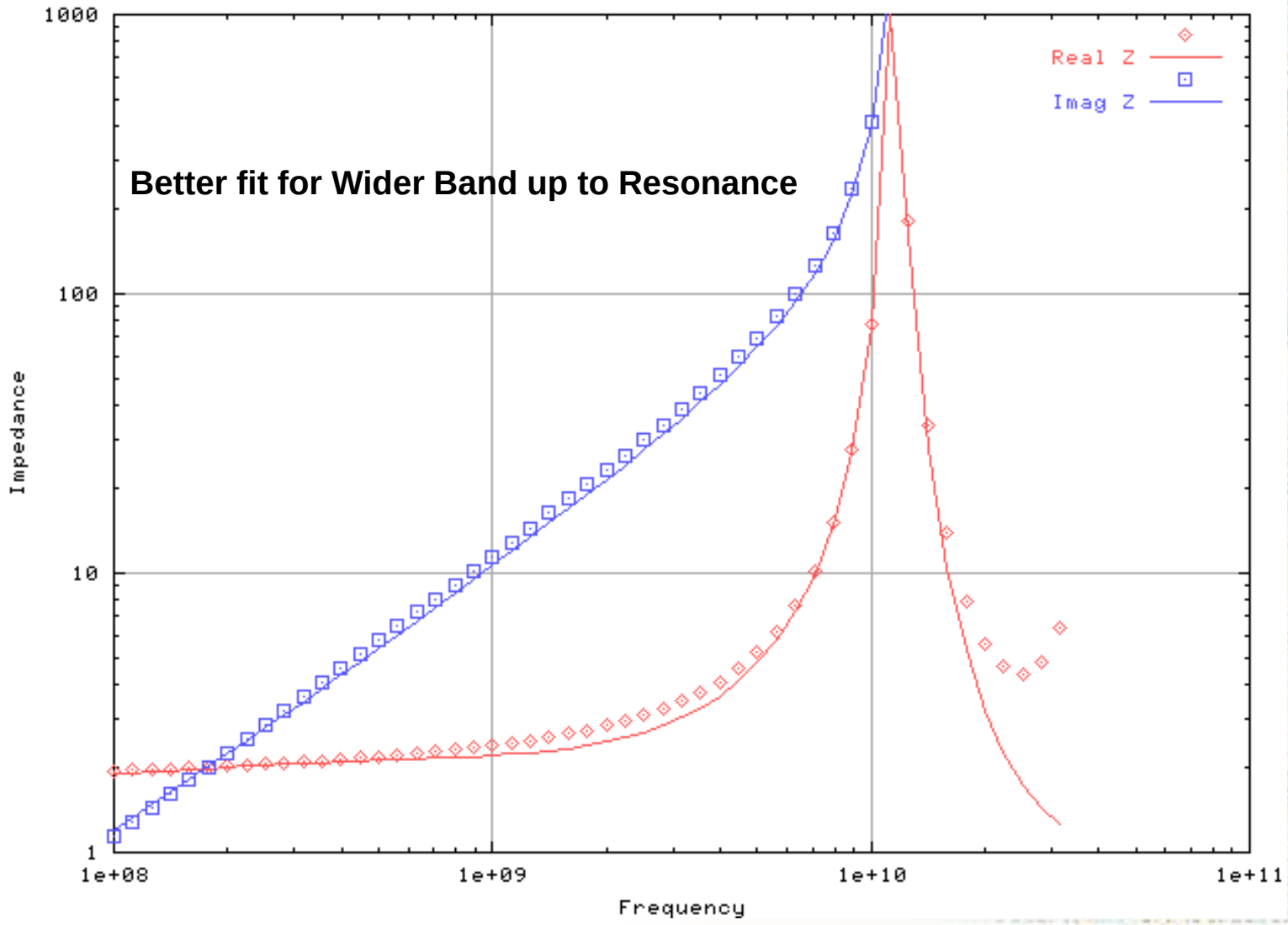


Narrow Band Fit

Wide Band Misfit

OEA International, Inc.

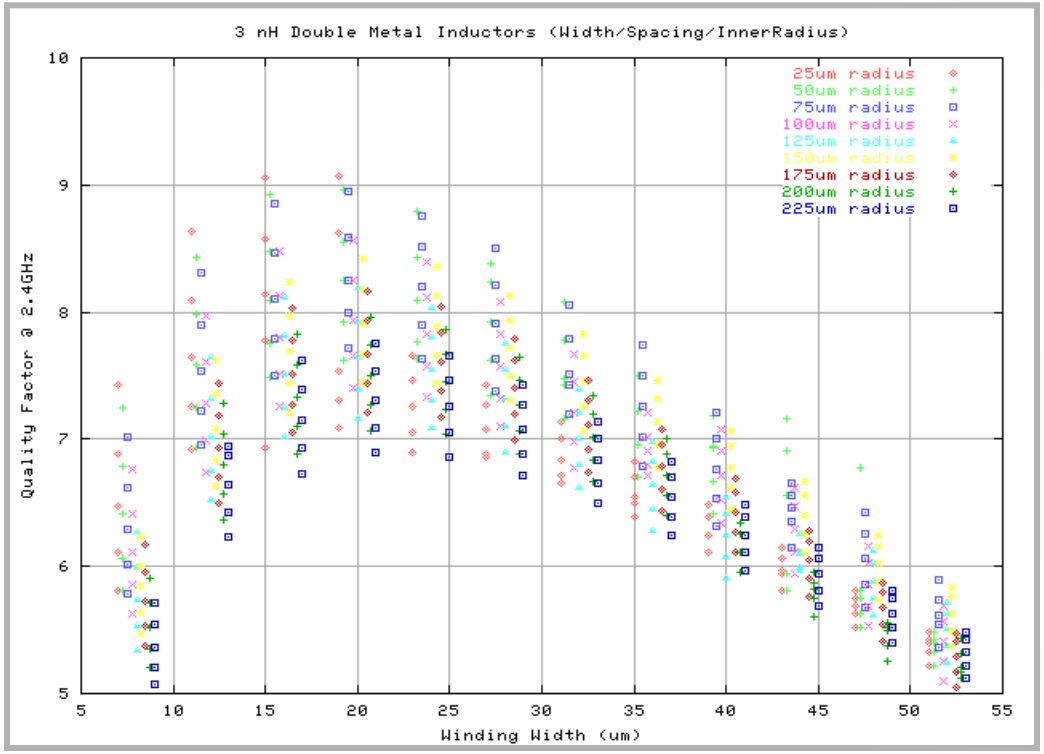
Broadband 13 Element Model Fit

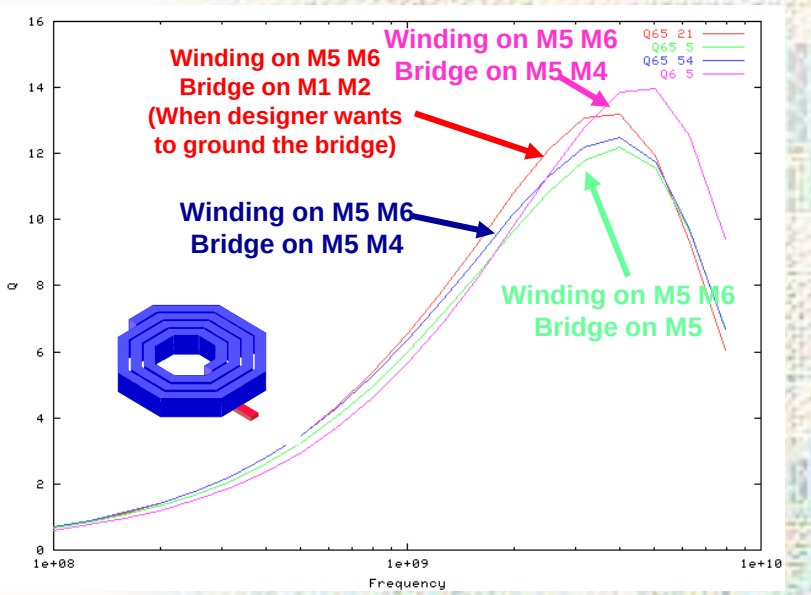


OEA International, Inc.

Spiral Value Proposition

Design Space Exploration & Optimum Device Synthesis



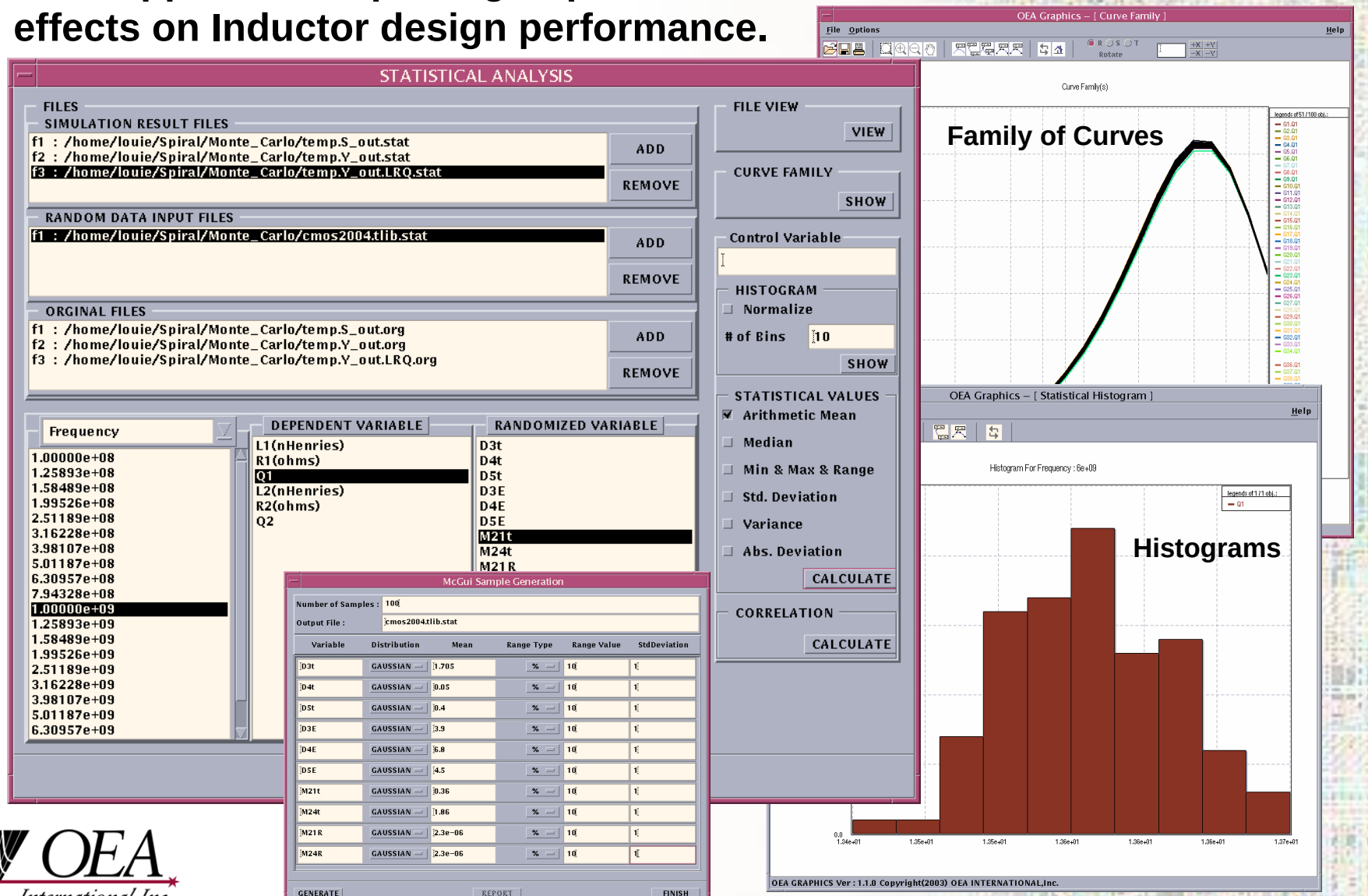


- Thousands of Solutions Synthesized
- Performance/Area Tradeoffs Easily Analyzed
- Guides Designer to Correct Implementation to Optimize

OEA International, Inc.

Spiral Monte Carlo Analysis

Full support and reporting of process variation effects on Inductor design performance.

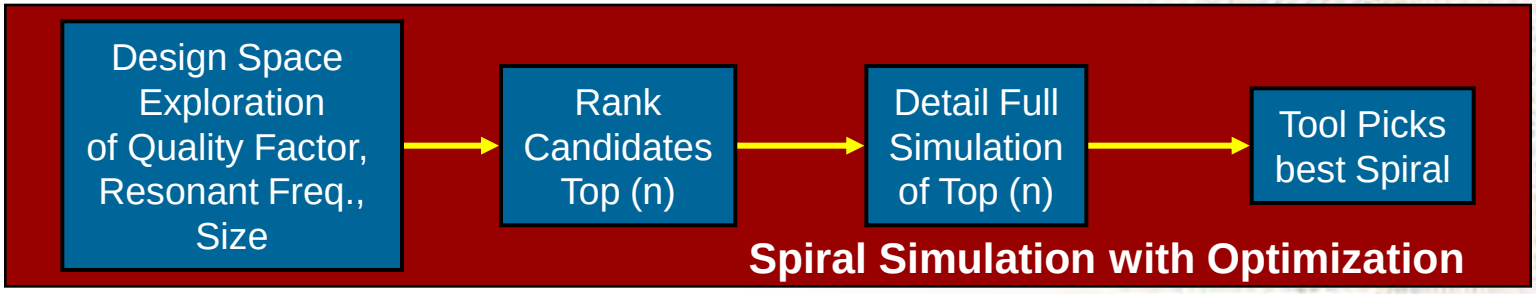


OEA International, Inc.

Spiral Value Proposition

Improved Design Performance/Quality

- Ease of Use Enables Deployment to Designer's Desktop
  - Tight Integration with Cadence Composer and Artist
  - No EM Knowledge Required

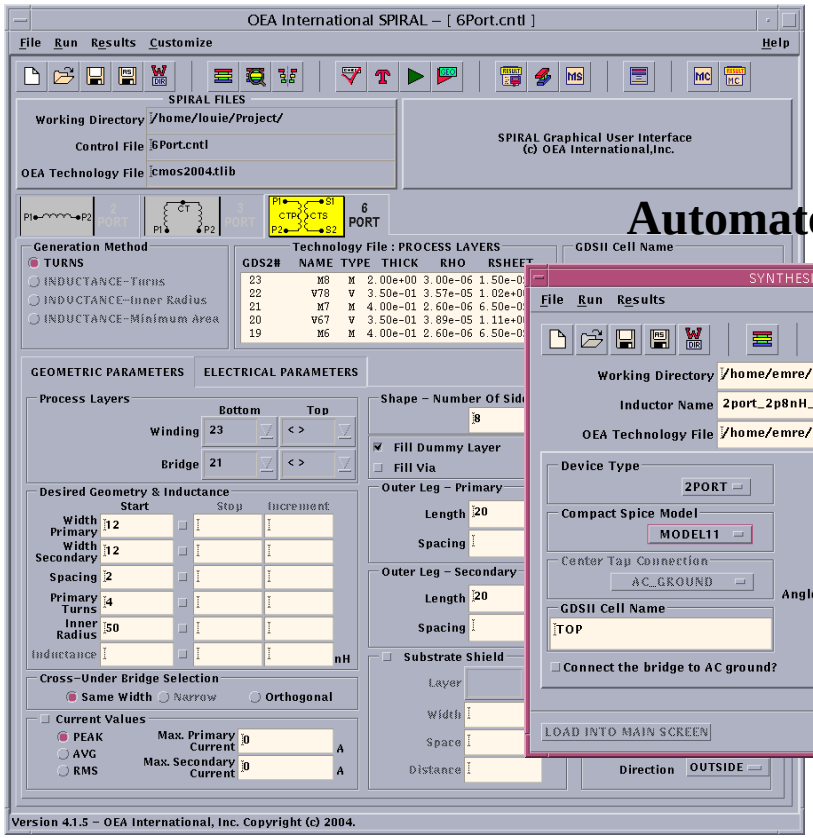


- Design Specific Component Optimization
  - By Frequency, Area, Port Locations
  - Better Yield: Models Include Process Variations

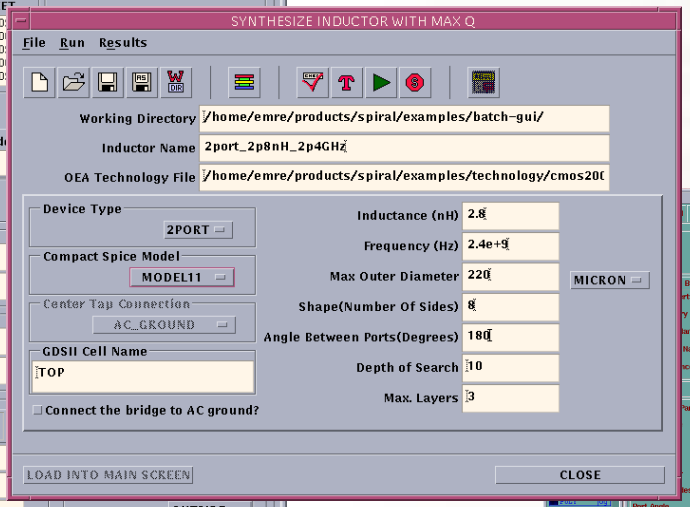
OEA International, Inc.

Spiral's Ease of Use
Enables Widespread Deployment

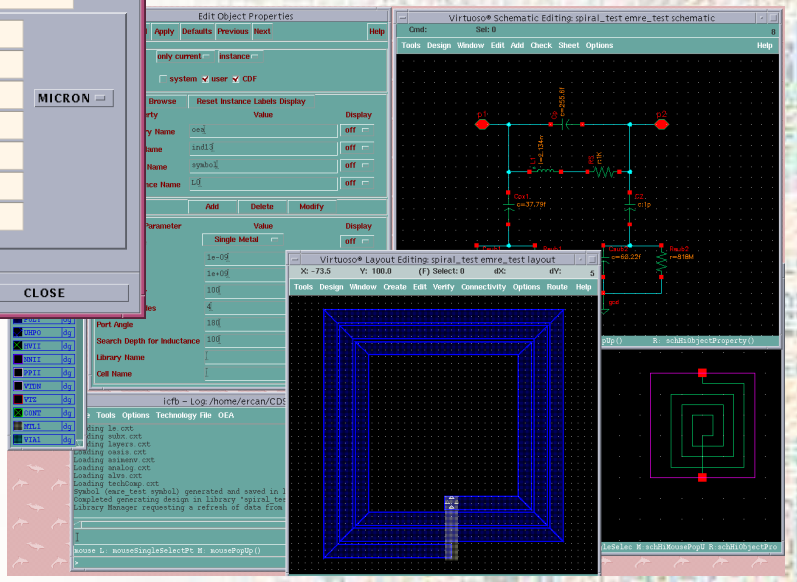
User Defined Geometry Mode



Automated Synthesis Mode

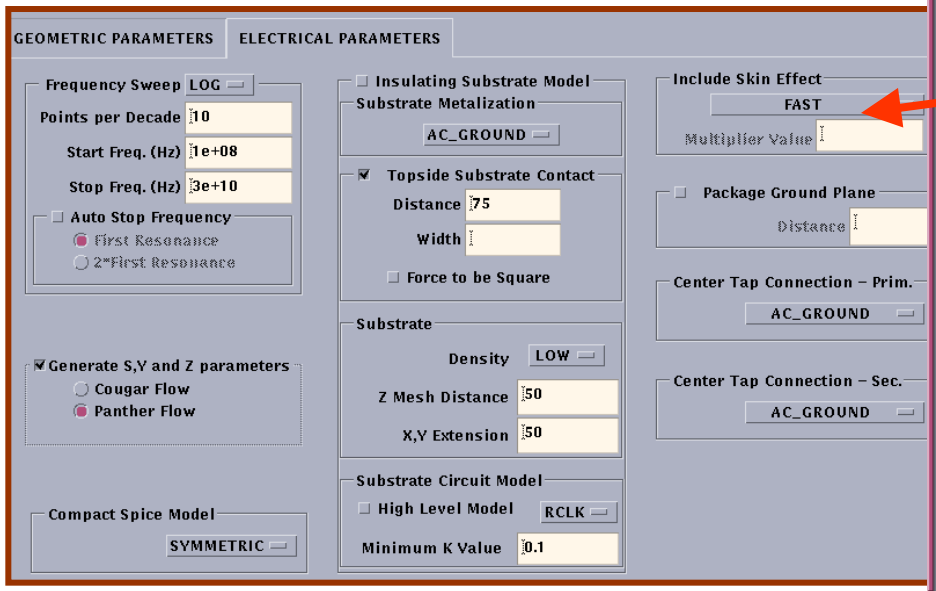


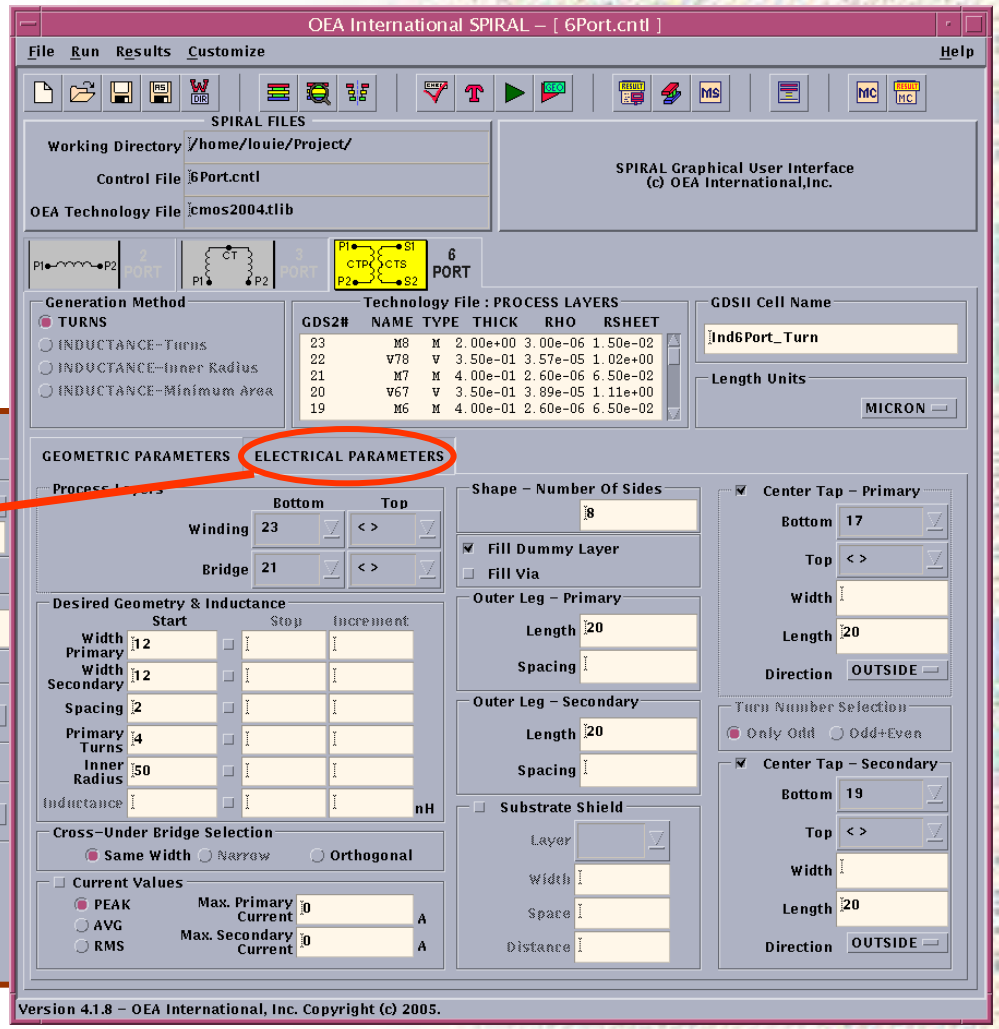
Cadence Integration



OEA International, Inc.

Full Range of Parameter Definitions for Customizing Inductor





OEA International, Inc.

Process Technology File Defines Physical Properties

```
TECHNOLOGY CMOS99
UNIT MICRONS          # Units of microns apply to all length dimensions below
METAL
#Order Layerno Name Type Z_min Thickness Resistivity J(PEAK     AVE         RMS)     EdgeBias
   1       1   POLY  P   0.350    0.200   1.56E-04   1.00E-03  0.00E+00  0.00E+00  0.00E+00
   2       2   CT    C       1        3   2.90E-04   1.00E-03  0.00E+00  0.00E+00  0.00E+00
   3       3   M1    M   1.050    0.530   4.13E-06   1.00E-03  0.00E+00  0.00E+00  0.00E+00
   4       4   V1    V       3        5   1.02E-04   1.00E-03  0.00E+00  0.00E+00  0.00E+00
   5       5   M2    M   2.380    0.530   4.13E-06   1.00E-03  0.00E+00  0.00E+00  0.00E+00
   6       6   V2    V       5        7   1.02E-04   1.00E-03  0.00E+00  0.00E+00  0.00E+00
   7       7   M3    M   3.710    0.530   4.13E-06   1.00E-03  0.00E+00  0.00E+00  0.00E+00
   8      10   V3    V       7        9   1.02E-04   1.00E-03  0.00E+00  0.00E+00  0.00E+00
   9      45   M4    M   5.040    0.530   4.13E-06   1.00E-03  0.00E+00  0.00E+00  0.00E+00
  10       8   V4    V       9       11   1.02E-04   1.00E-03  0.00E+00  0.00E+00  0.00E+00
  11      50   M5    M   6.370    0.530   4.13E-06   1.00E-03  0.00E+00  0.00E+00  0.00E+00
  12       9   V5    V      11       13   1.26E-04   1.00E-03  0.00E+00  0.00E+00  0.00E+00
  13      51   M6    M   7.700    3.000   3.56E-06   1.00E-03  0.00E+00  0.00E+00  0.00E+00
ENDMETAL
DIELECTRIC
#Order Type Thickness  Epsilon(z     x       y)
1      p     0.350     3.90E+00  3.90E+00  3.90E+00  #  Si usually starts with a field oxide
2      p     0.700     4.00E+00  4.00E+00  4.00E+00  #
3      p     6.650     3.80E+00  3.80E+00  3.80E+00  #
4      p     4.000     4.20E+00  4.20E+00  4.20E+00  #
5      p     0.700     7.90E+00  7.90E+00  7.90E+00  #  Passivation layer
6      p    10.000     1.00E+00  1.00E+00  1.00E+00  #  Air
ENDDIELECTRIC
SUBSTRATE
#Order Name    DopingType  Thickness Resistivity   Epsilon(z  x         y)
-1    epi         p             2.0       0.1       11.9      11.9      11.9
-2    bulk        p           600.0      10.0       11.9      11.9      11.9
-3    metal       p             3.0       3.0e-6     1.0       1.0       1.0
ENDSUBSTRATE
DRCRULES
enclosure 51 9 0.5      # Layer 51 (M6) encloses layer 9 (V5) by 0.5 um
enclosure 50 9 0.1      # Layer 50 (M5) encloses layer 9 (V5) by 0.1 um
viasize    9  0.7       # Layer  9 (V5) size is 0.7 um
minspace   9  0.7       # Layer  9 (V5) spacing is 0.7 um between vias
minwidth  51  3.0       # Minimum width for layer 51 (M6) is 3.0 um
minwidth   $  1.0       # Minimum width for all non M6 metal or poly layers is 1.0 um
minspace   $  2.0       # Minimum space for all remaining layers is  2.0
gridsnap      0.01      # Snap all vertices to the nearest hundreth of a micron
ENDDRCRULES
ENDTECHNOLOGY
```

Spiral Value Proposition

Advantages Over Pre-Characterized Libraries

Pre-Characterized Libraries

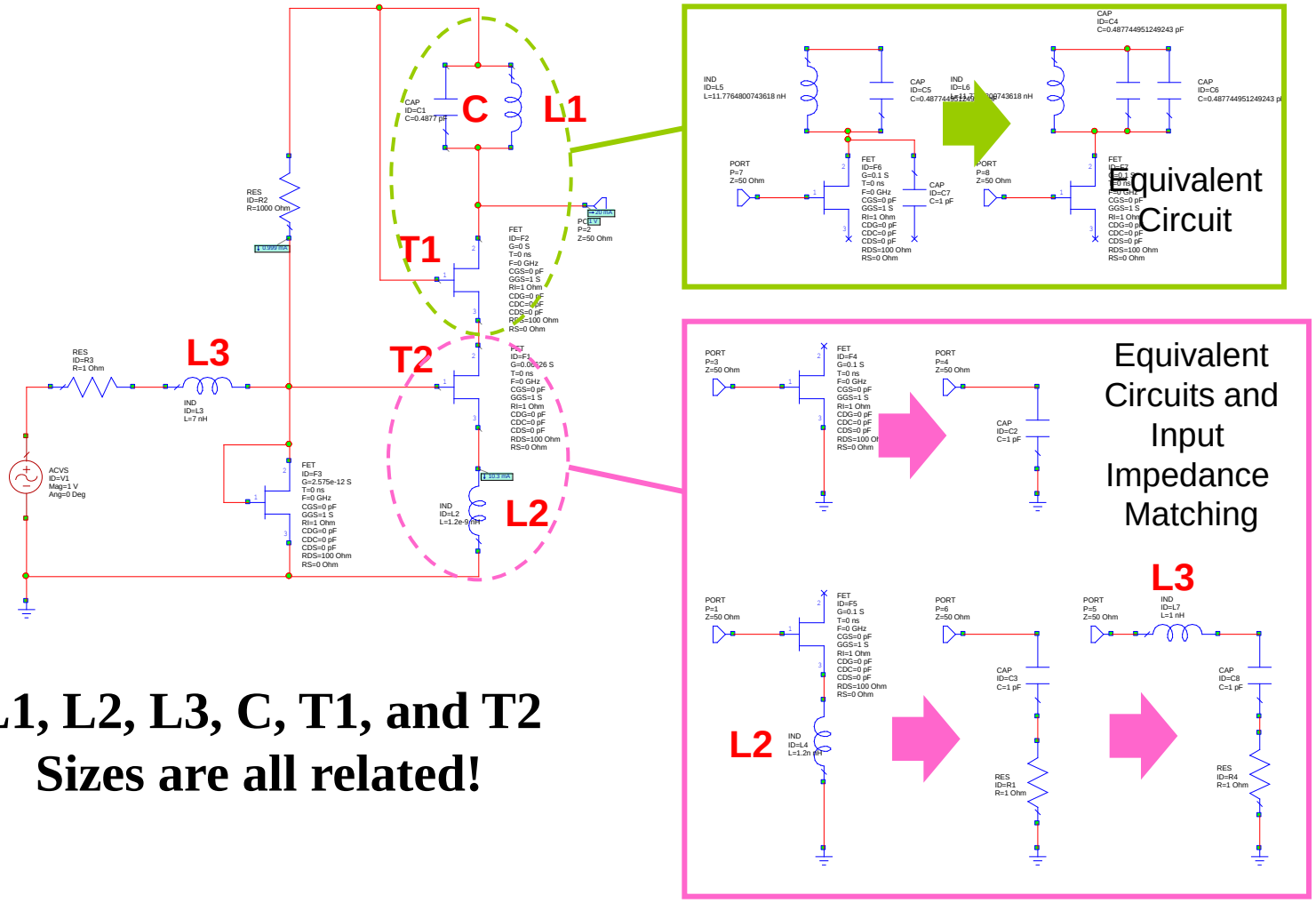
1. Accurate
2. Only specific Inductors Allowed can dramatically limit design
3. Very significant design and measurement effort
4. Available after running test chips only
5. Extensive rework if process is changed

SPIRAL

1. Accurate
2. Inductors optimized for particular design
3. Minimum possible effort
4. Available immediately
5. Process changes easily incorporated

OEA International, Inc.

Why Optimized Spirals are Critical in an LNA



L1, L2, L3, C, T1, and T2 Sizes are all related!

Tuning cannot easily be achieved with a predefined library of inductors

OEA International, Inc.

Spiral Value Proposition
Advantages Over Full Wave Solvers

Full Wave Solvers

1. Analysis tool
2. Electromagnetic expertise required
3. Extensive tool experience
4. Accurate (for experts) beyond resonance but difficulty at very low frequencies
5. Hours to generate input plus several hours to run analysis on a single inductor
6. Output is S-Parameters requires separate fitting step to get SPICE
7. Not integrated with design environments

SPIRAL

1. Synthesis Tool
2. No EM expertise required – easily used by RF designers
3. Minimum training required
4. Accurate up to resonance and very accurate low frequency results
5. Whole process runs in seconds or minutes including generation of fit models
6. Automated SPICE models both distributed and lumped available
7. Completely integrated with Cadence Composer & Artist

OEA International, Inc.

Spiral Value Proposition
Advantages Over Analytical Tools

Analytical Tools

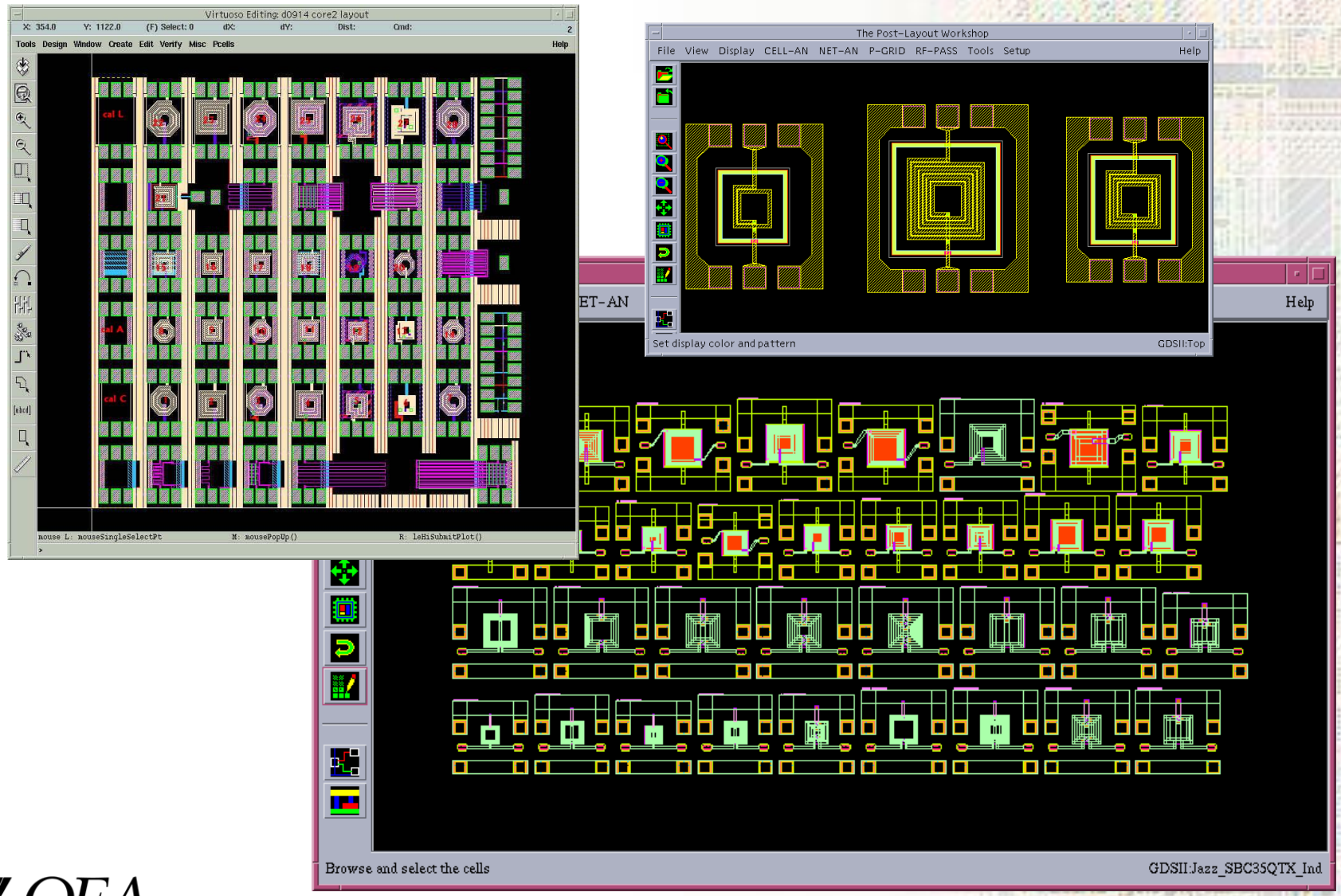
1. Analysis tool
2. Cheap – sometimes free
3. Difficult to use
4. Accurate DC results, extreme difficulty with RF results
5. Outputs are incomplete – does not include S, Y and Z parameters, plots of LRQ, layouts, etc…
6. Separate fitting step to get lumped SPICE models
7. Not integrated with design environments

SPIRAL

1. Synthesis Tool
2. Commercial Product
3. Very easy to use
4. Accurate DC results & highly accurate up to resonance
5. Complete set of outputs including S, Y and Z parameters, LRQ, DRC correct layouts etc…
6. Automated SPICE models both distributed and lumped available
7. Completely integrated with Cadence Composer & Artist

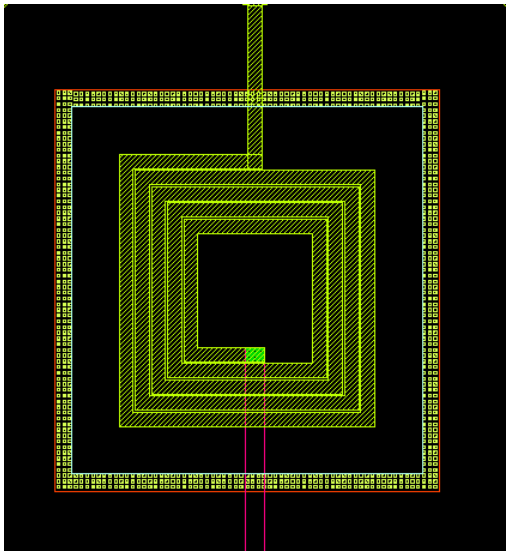
OEA International, Inc.

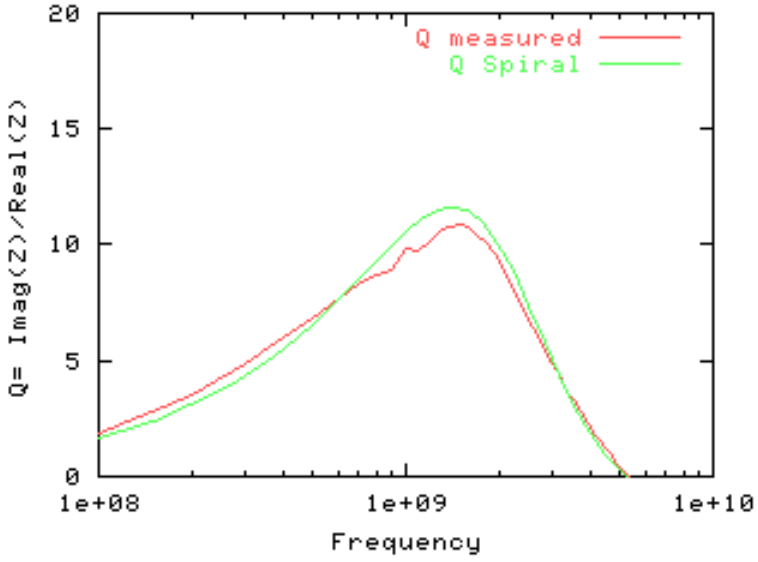
Sprial Extensively Validated Using With Customers and Test Chips

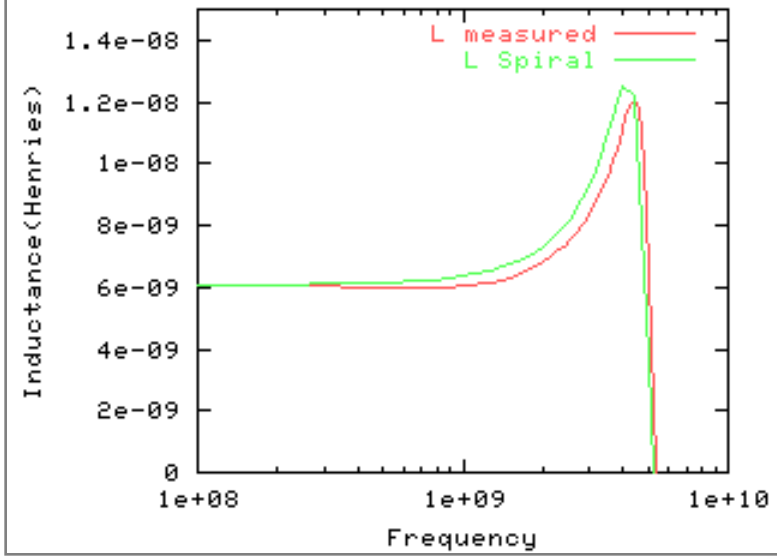


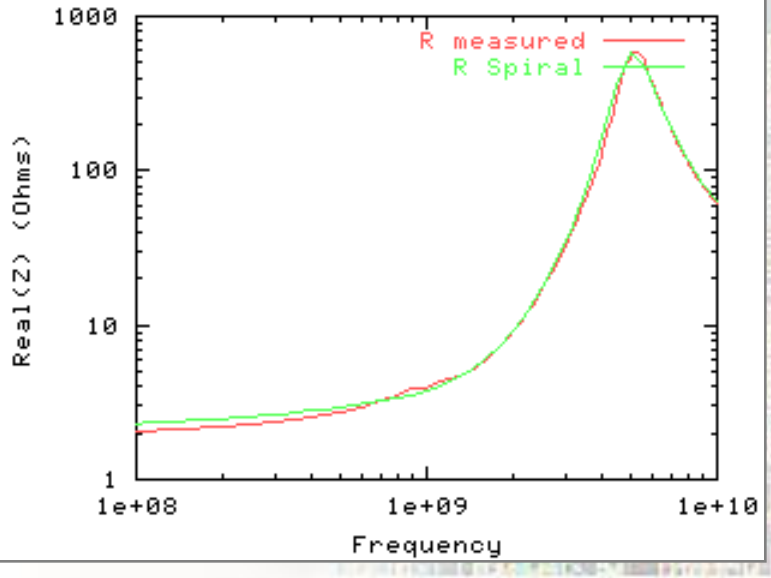
OEA International, Inc.

LRQ over Frequency Comparison Against Foundry Measurements (0.13 um Process)

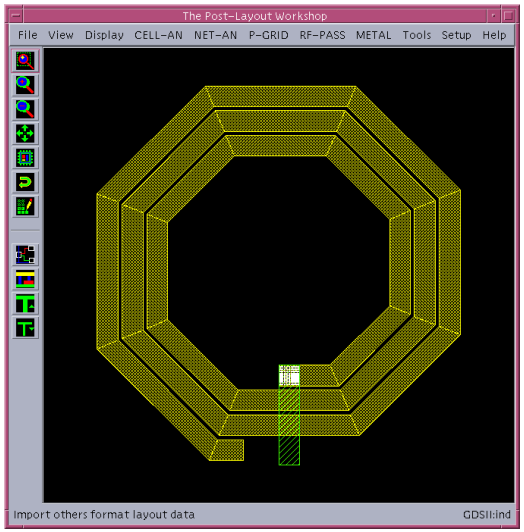


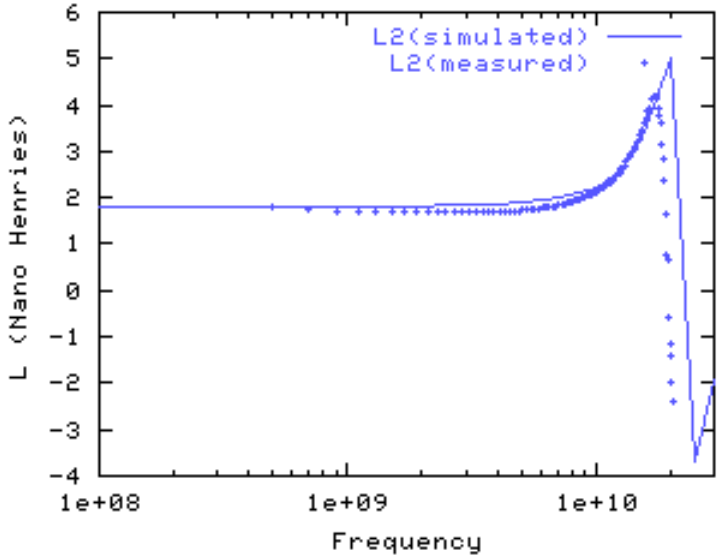


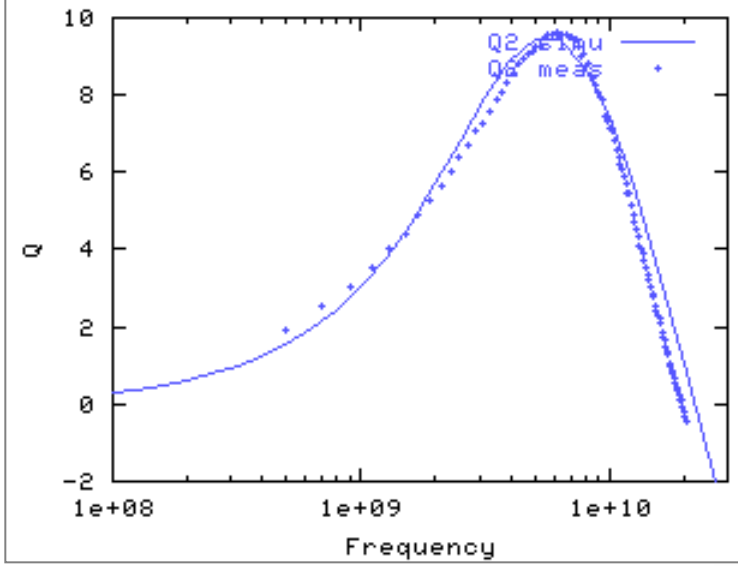


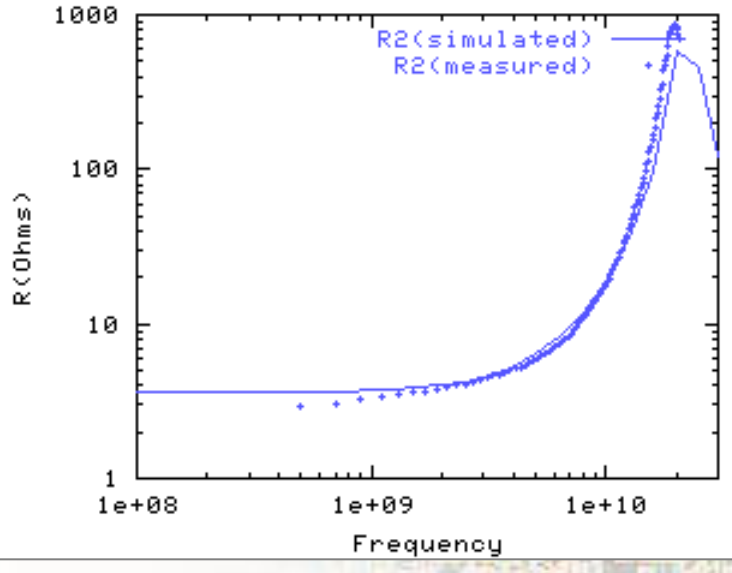


Asian Foundry: Measured Versus Simulated (0.18 um Process)

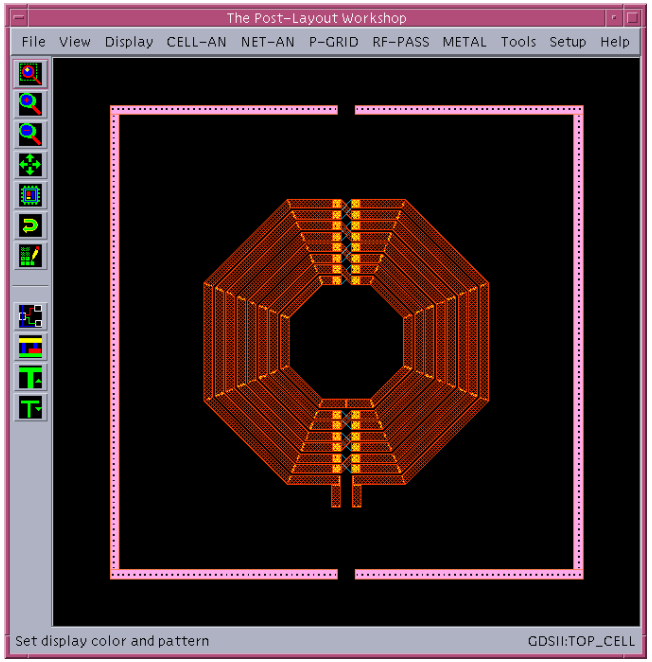


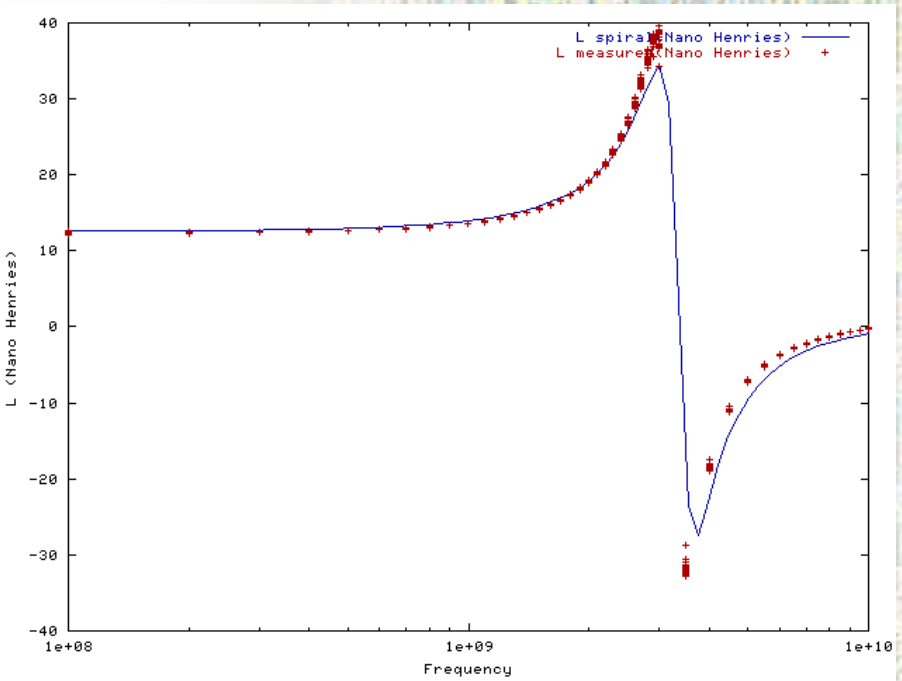


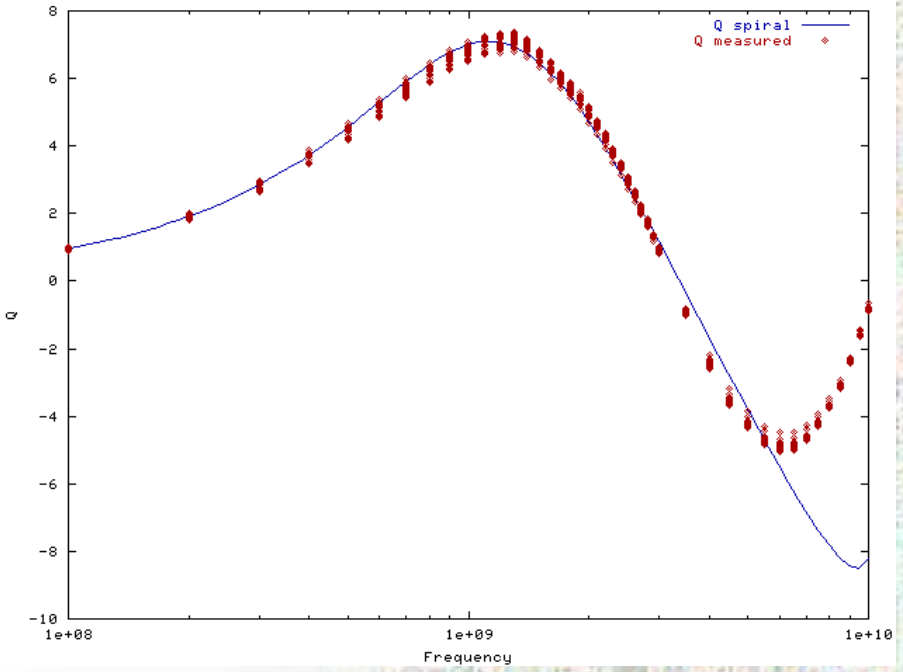




Measured versus simulated across multiple lots and wafers (0.18 um Process)







OEA International, Inc.

Summary

- Fully Automatic Inductor Synthesis
  - Circuit Specific Inductor Optimization
    - Evaluates 1000's of Alternatives in Seconds
  - Easy to Use and Deploy
    - Library Development or Designer's Desktop
- High Accuracy Models Match Silicon
  - Improves Overall Design Performance
- Ready for 90nm & 65nm Technologies
  - Slotting and Dummy Metal Fill

OEA International, Inc.

Inductance Calculation in Spiral

OEA International, Inc.

Partial Inductance Approach

Six Self Inductances: $L_1, L_2, L_3, L_4, L_5, L_6$

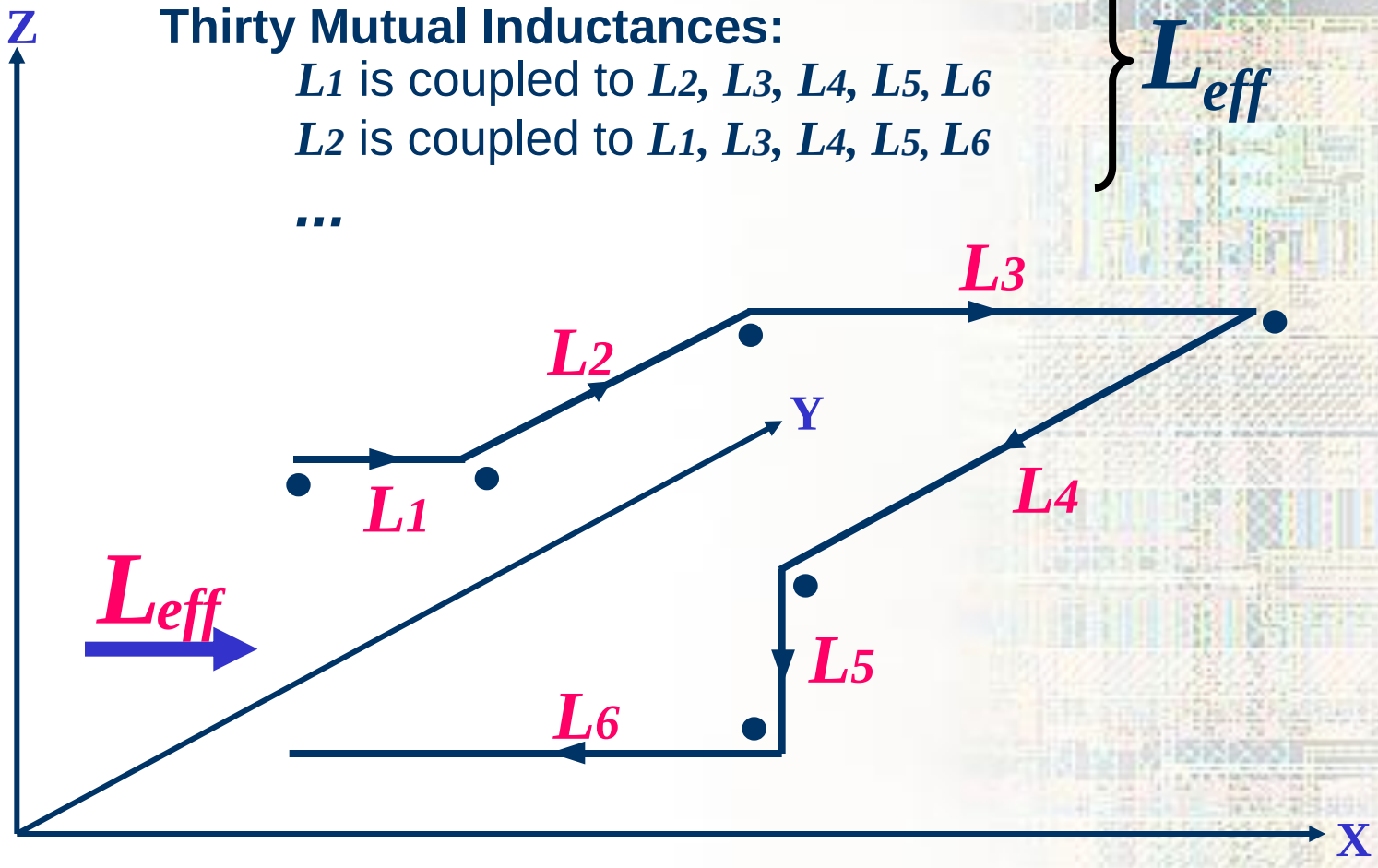
Thirty Mutual Inductances:

L_1 is coupled to L_2, L_3, L_4, L_5, L_6

L_2 is coupled to L_1, L_3, L_4, L_5, L_6

...

L_{eff}



OEA International, Inc.

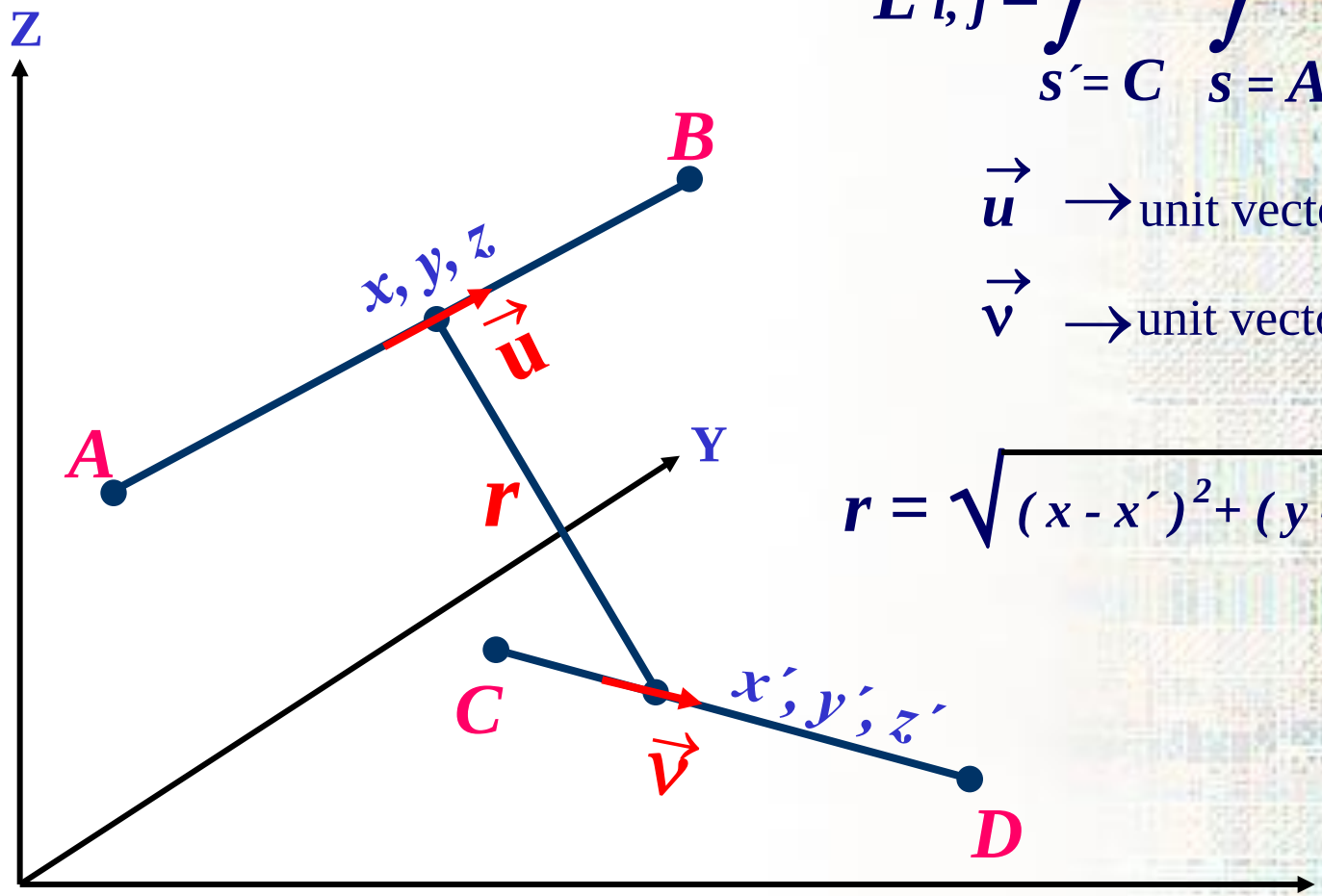
Neumann Formulation of Mutual Inductance

$$L_{i,j} = \int_{s'=C}^{D} \int_{s=A}^{B} \frac{\vec{u}\,\vec{v}}{r}\, ds\, ds'$$

$\vec{u}$ → unit vector along AB

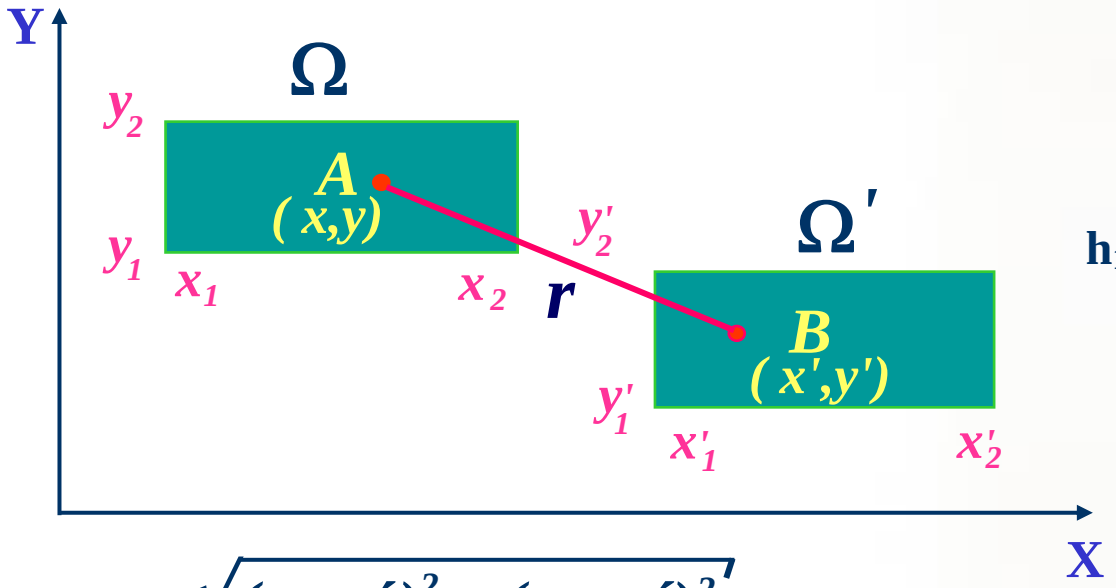
$\vec{v}$ → unit vector along CD

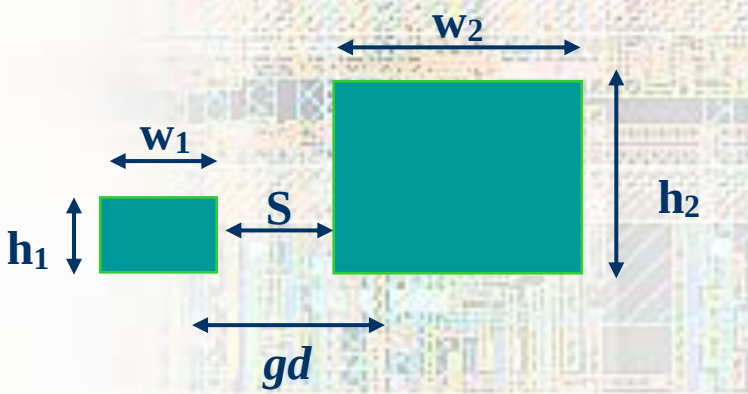
$$r = \sqrt{(x-x')^2 + (y-y')^2 + (z-z')^2}$$

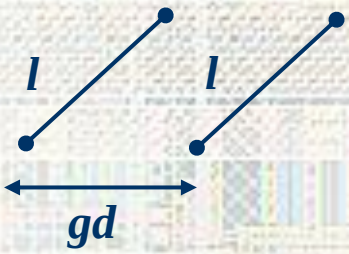


OEA International, Inc.

Geometric Distance Between Objects







$$r = \sqrt{(x - x')^2 + (y - y')^2}$$

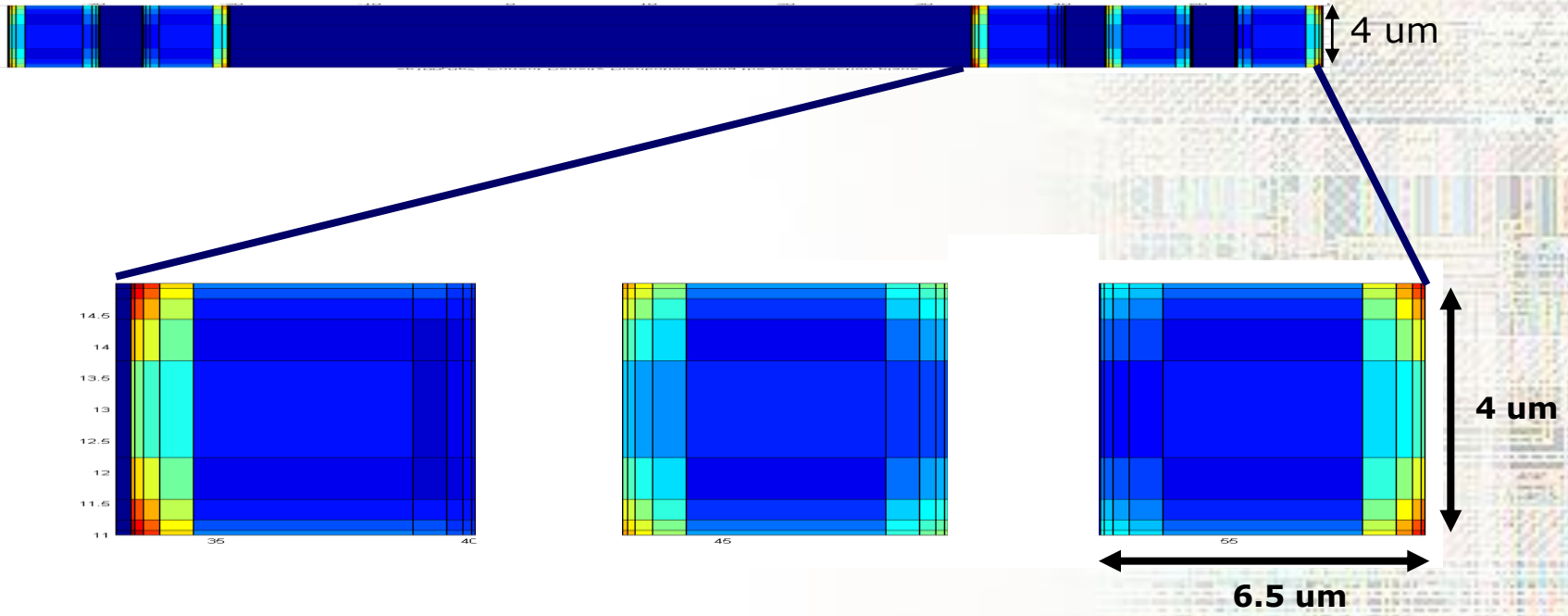
$$gd = \int_{\Omega'} \int_{\Omega} \ln(r)\, d\Omega\, d\Omega'$$

$$gd = \int_{y' = y_1'}^{y_2'} \int_{y = y_1}^{y_2} \int_{x' = x_1'}^{x_2'} \int_{x = x_1}^{x_2} \ln \sqrt{(x - x')^2 + (y - y')^2}\, dx\, dx'\, dy\, dy'$$

OEA International, Inc.

Current Distribution Due to Skin and Proximity Effects

2.5 Turn Square Spiral
100 um Inner Diameter
6.5 um Width
4 um Thickness
2.1 um Spacing



OEA International, Inc.