New Methodology for Spiral Inductor Design

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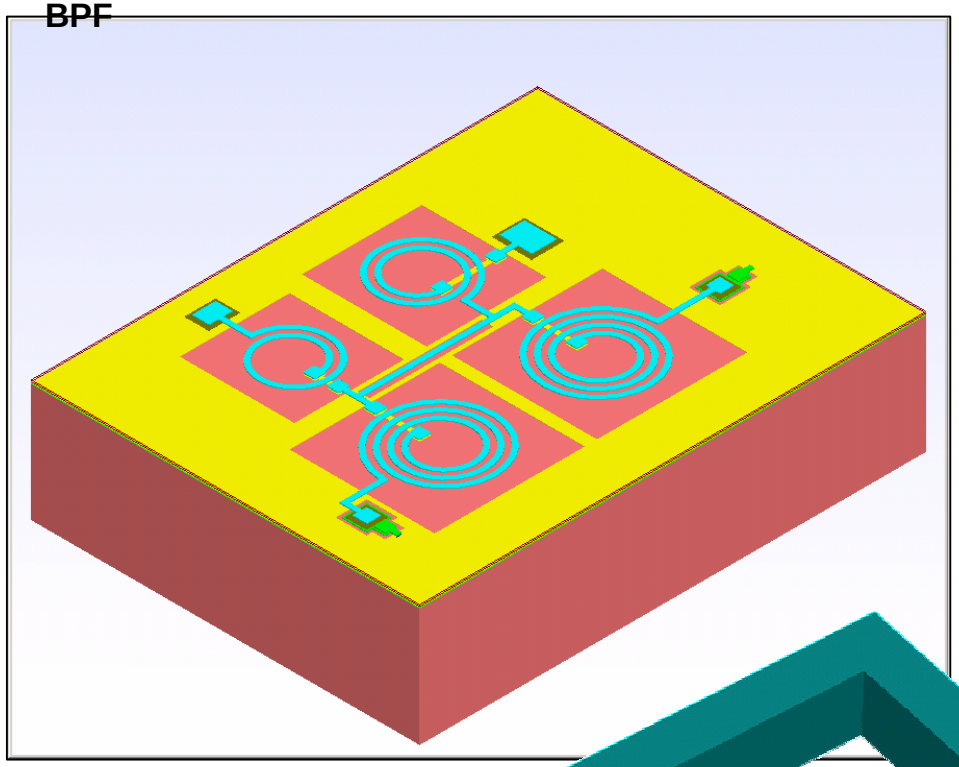
UMC

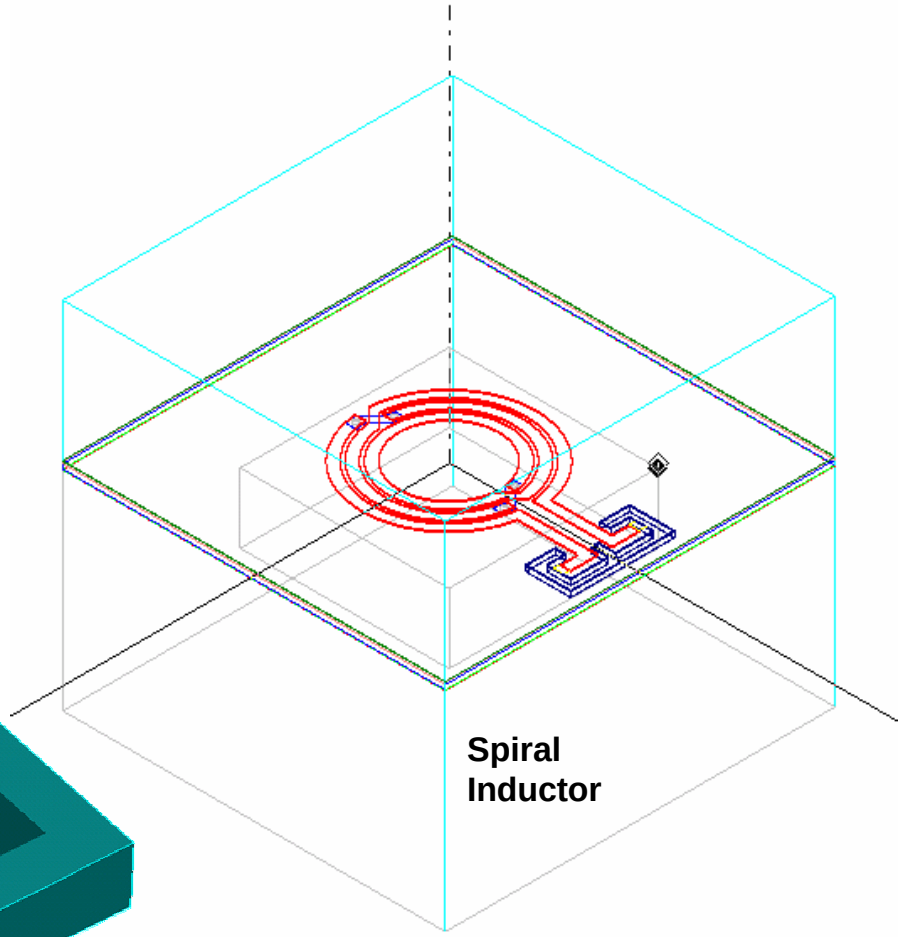
Outline

- Introduction
- Inductor Library from Foundry
- Customer Request on Inductor
- EM Design Methodology for Inductor
- Results and Comparison
- Other Application using EMDM
- Conclusion

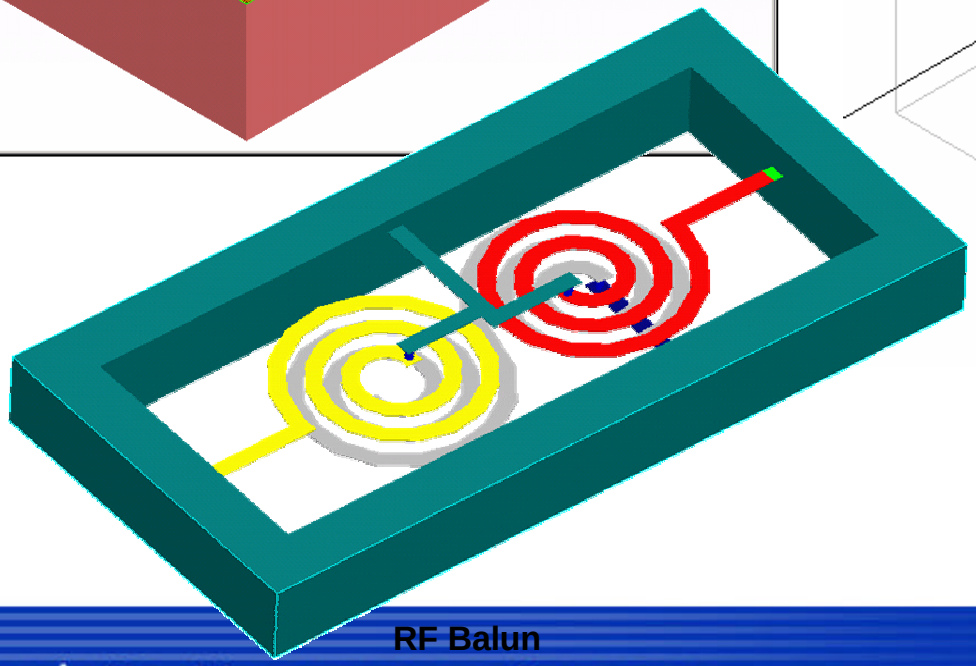
On-Chip Spirals

BPF



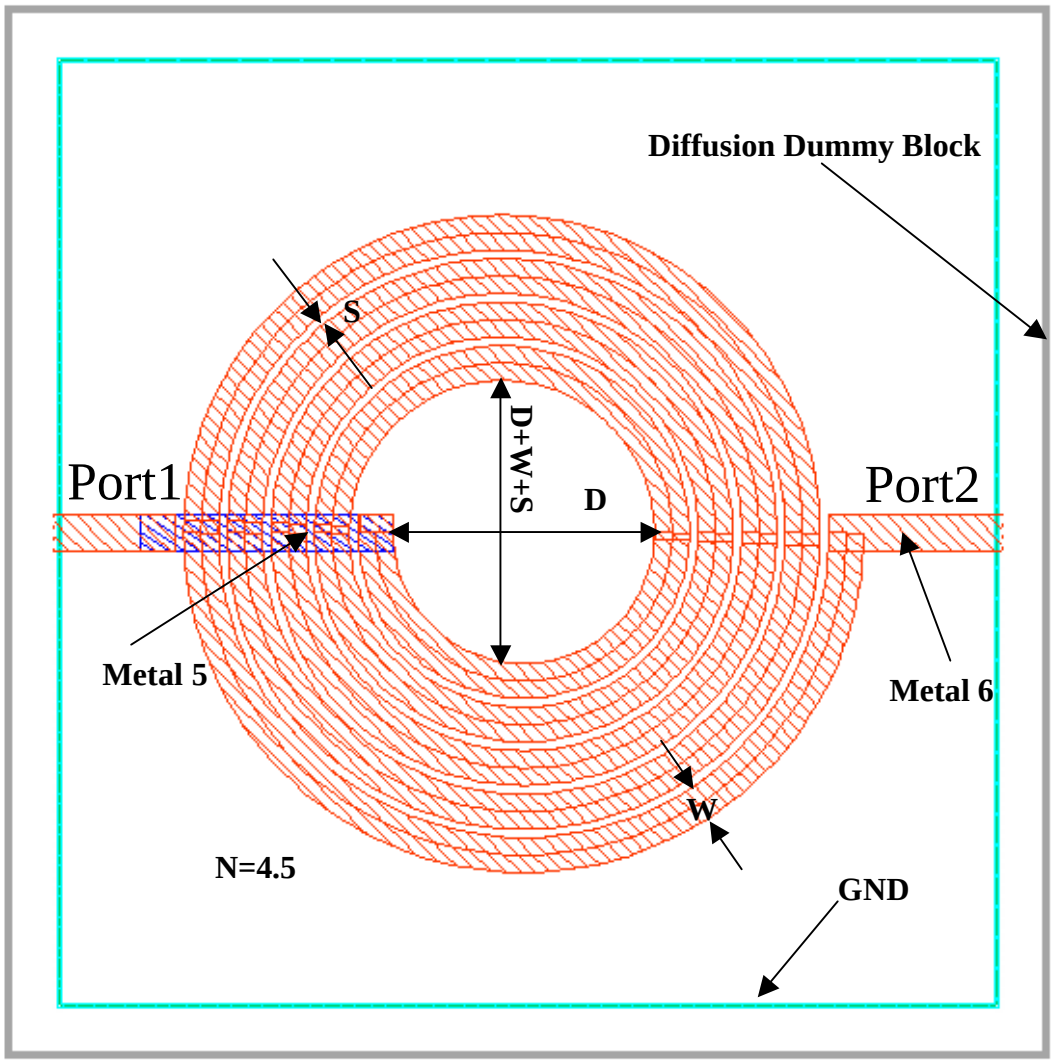


Spiral Inductor



RF Balun

Ideal Circular Inductor



Geometrical Parameter

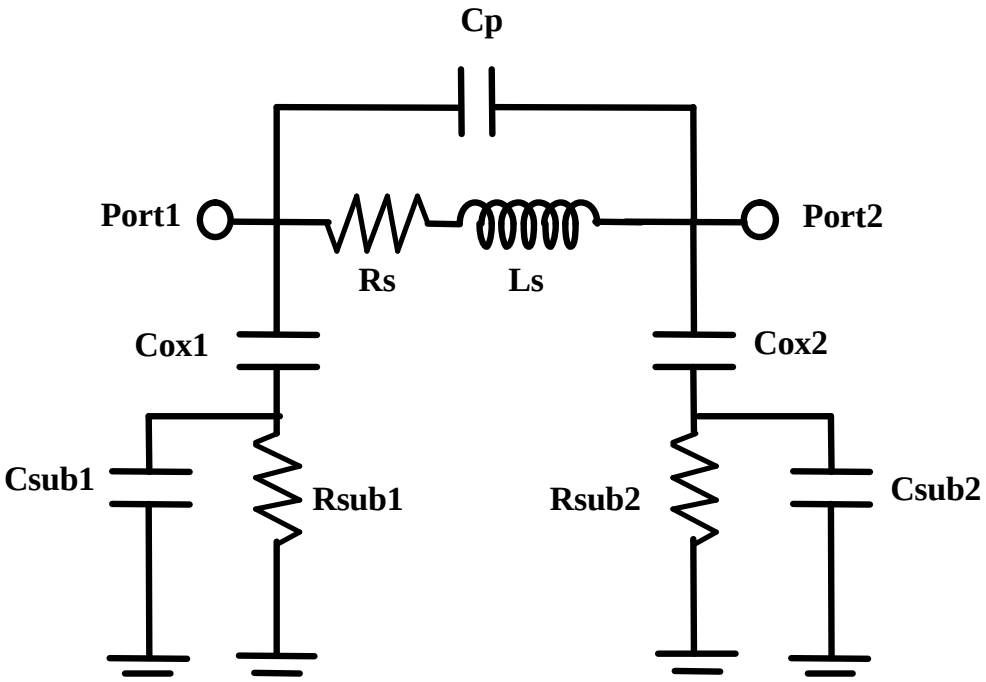
Diameter

Number of Turn

Width of Trace

Space between Trace

Inductor Equivalent Model



Spiral in CMOS

- Sheet resistance of metal layer can be used only for calculating the DC resistance of the spiral.
- Due to the skin effect, eddy current and "current crowding", the resistance of the spiral increases at high frequency.
- Copper metal and thick top-level metal to improve the maximum inductor *Q.*
- Multiple levels of metal strapped together to create a spiral with a lower dc resistance.
- PGS: pattern ground shield reduce the substrate loss
- CMOS substrate losses still the limiting factor

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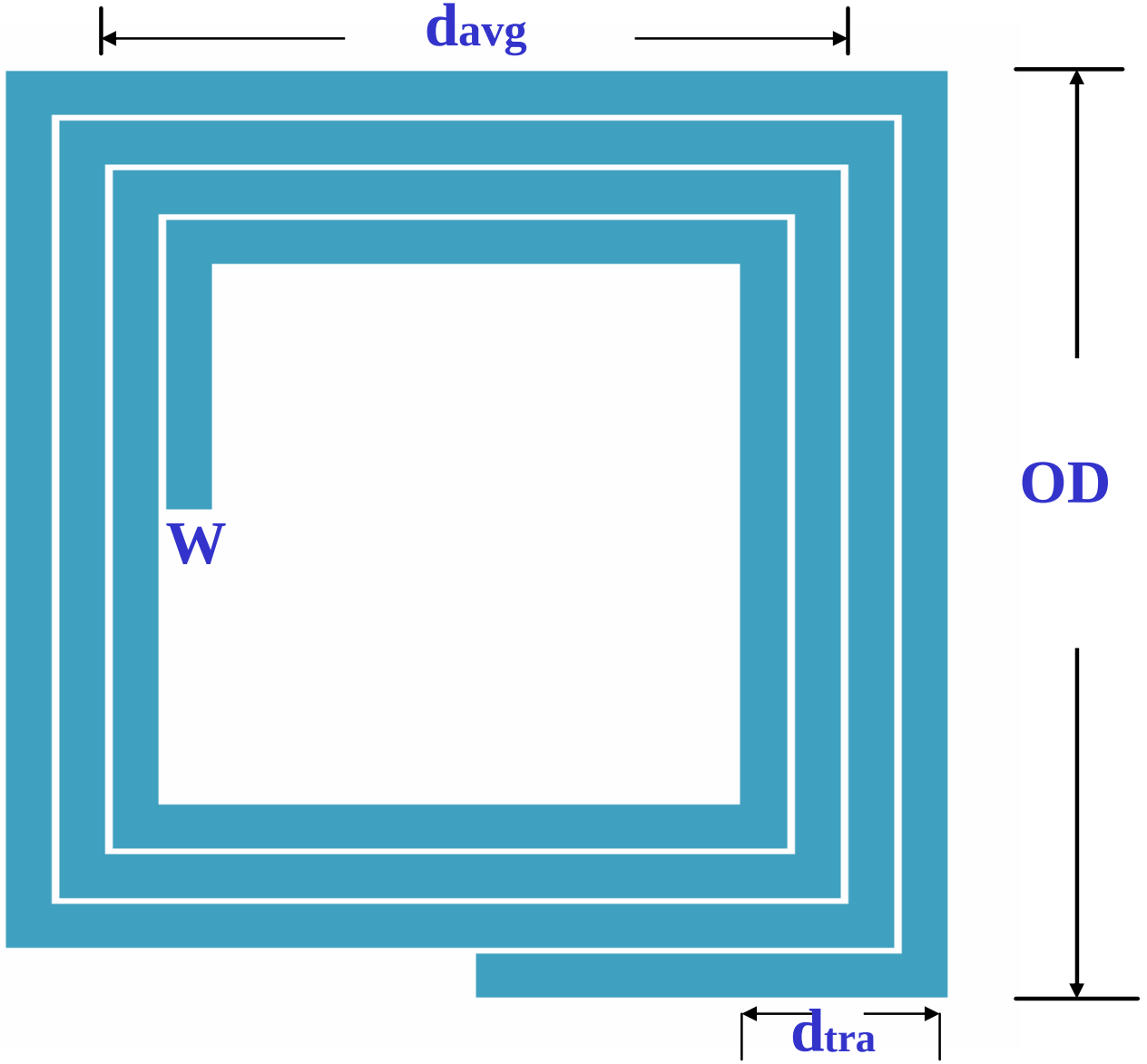
Foundry's Inductor Model and Library

- Empirical formula
- Direct measured inductor library
- Scalable model inductor library

Empirical Formula

$$r = \frac{d_{trace}}{d_{avg}}$$



Empirical Formula

n : number of turns.

μ : permeability of free space

*d*avg: average diameter

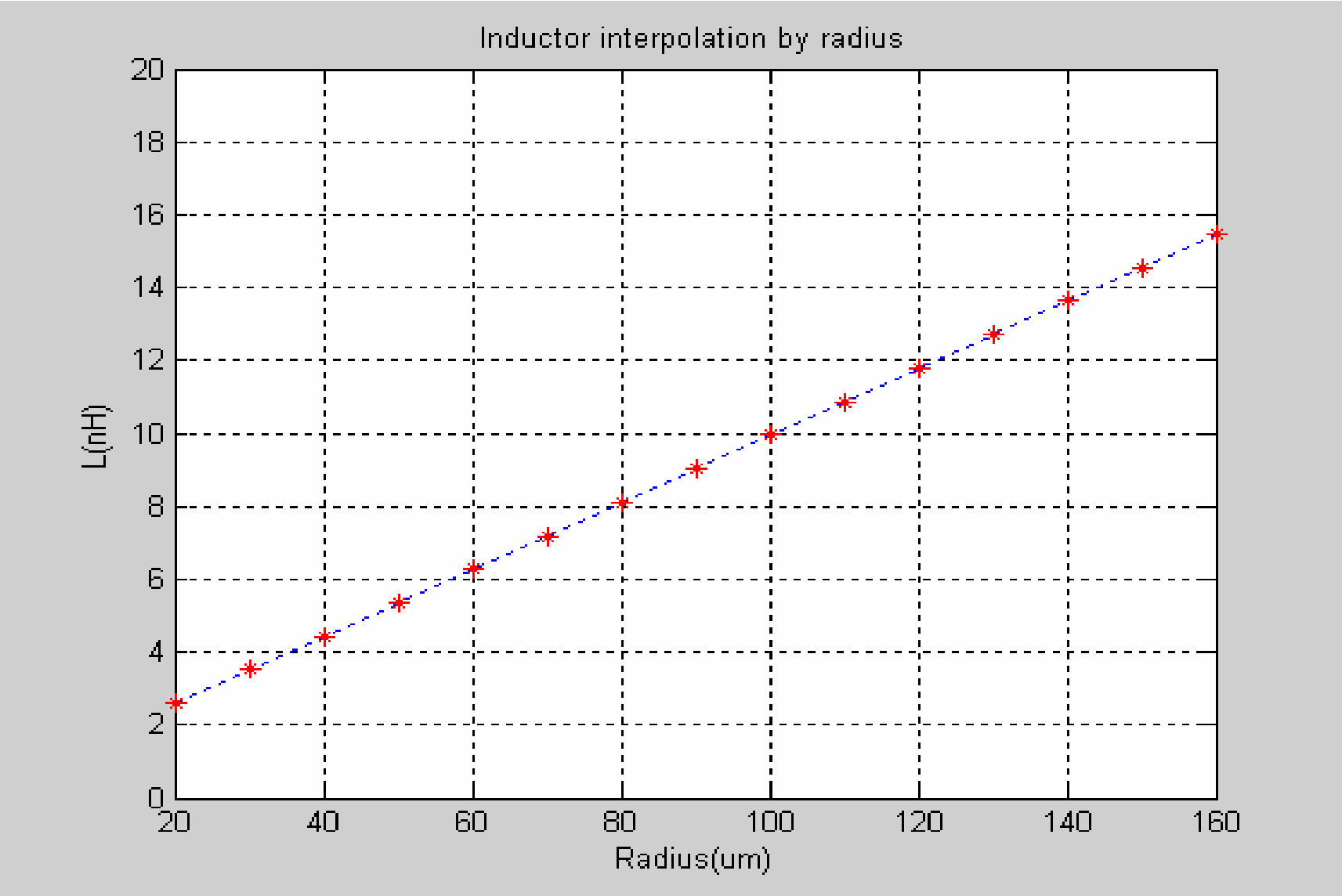
r : percentage of the inductor area that is filled by metal traces.

$$L = \frac{2mn^2 d_{avg}}{p}\left[\ln\left(\frac{2.067}{r}\right) + 0.178r + 0.125r^2\right]$$

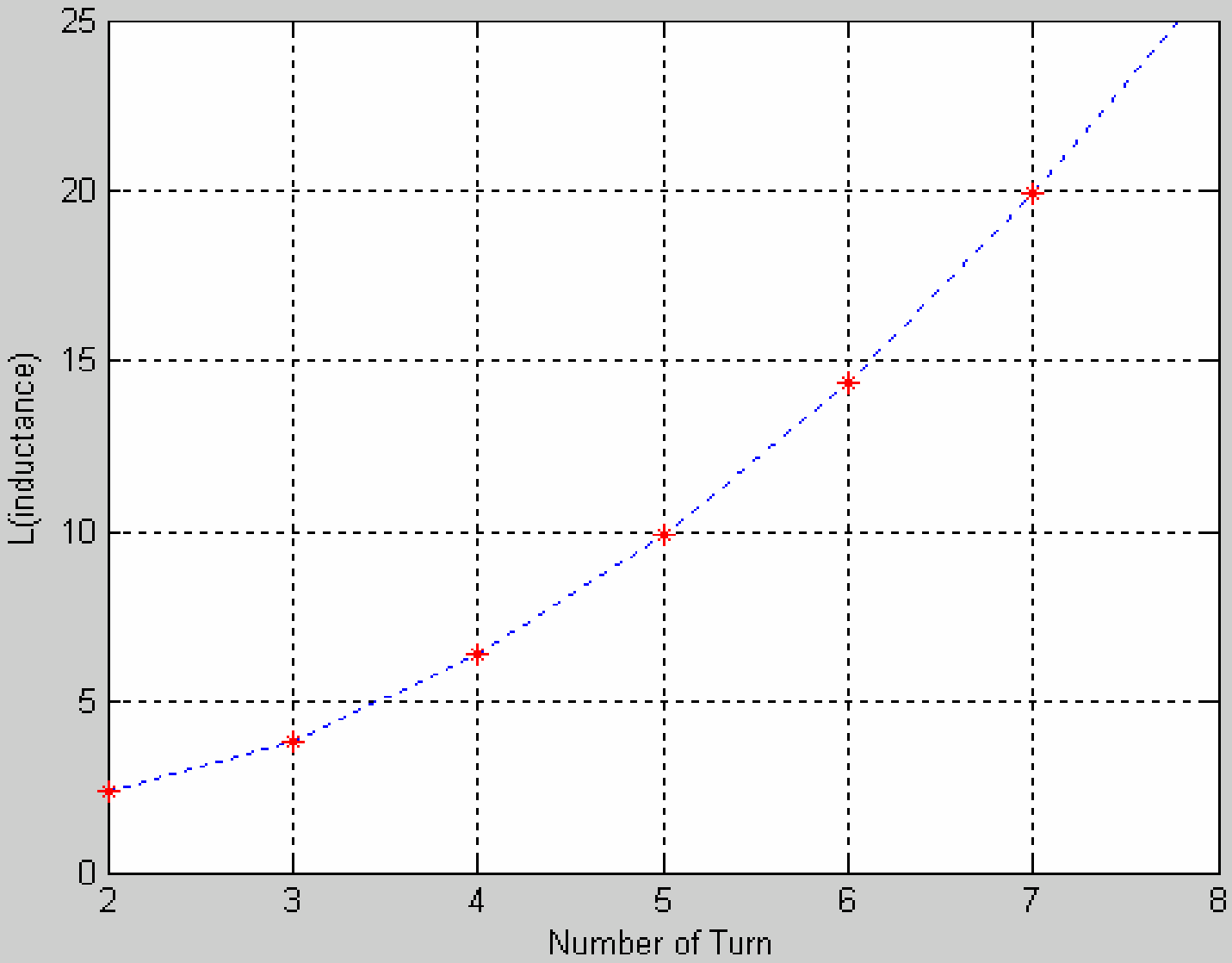
Measured Inductor Library

- Library dimension factory
  - Radius
  - Number of turns
  - Width of Trace
- Square Spiral
- Circular Spiral
- Ind_C1 to Ind_C20
- L: 0.98 ~25(nH)
- Q: 16 ~ 3.6 (5.6GHz), 10 ~ 7 (2.4G)

Scalable Inductance v.s. radius



Scalable Inductance v.s. turns



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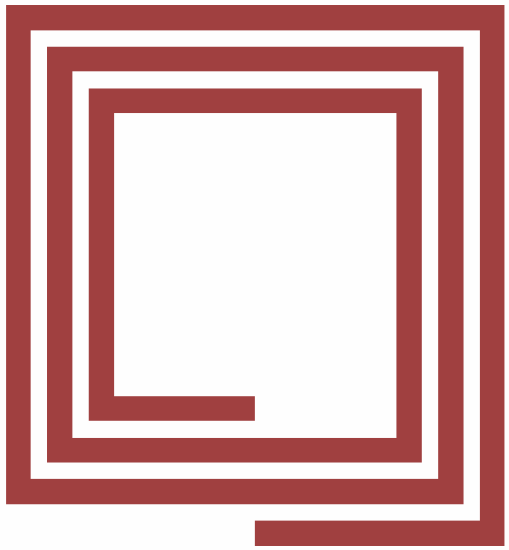
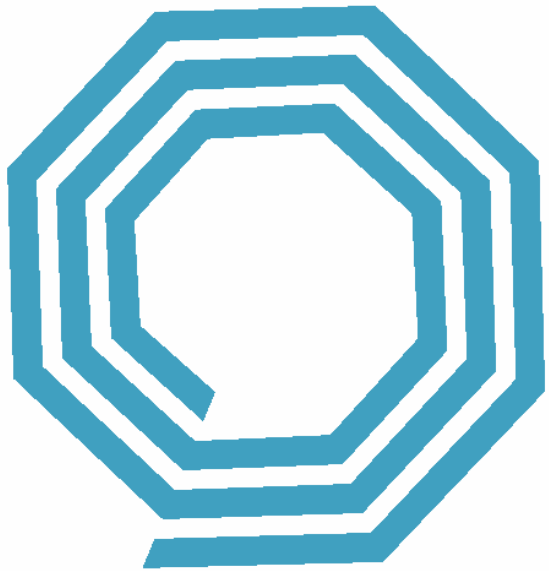
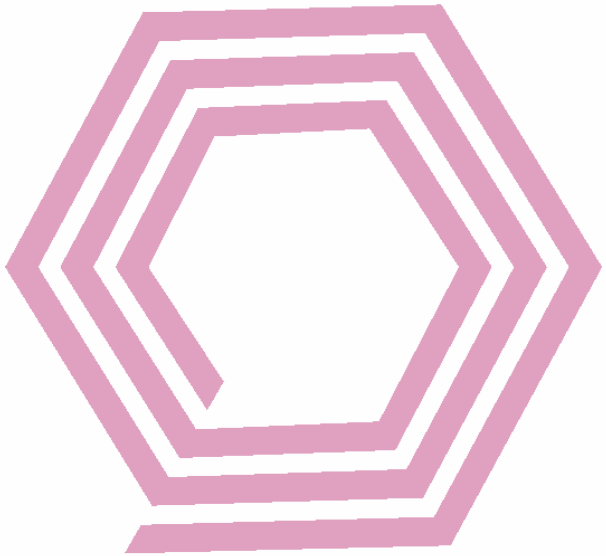
Various Spiral

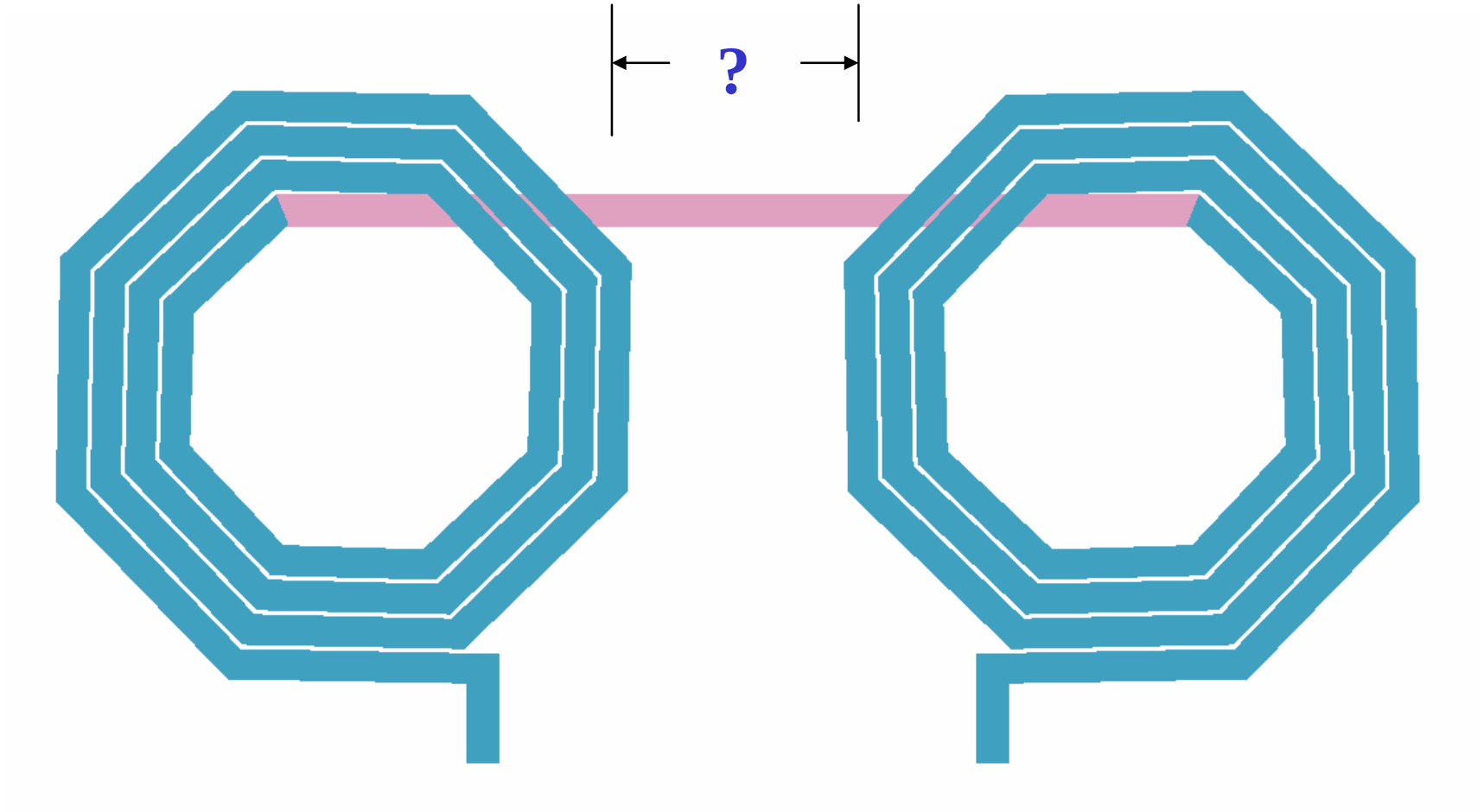


?

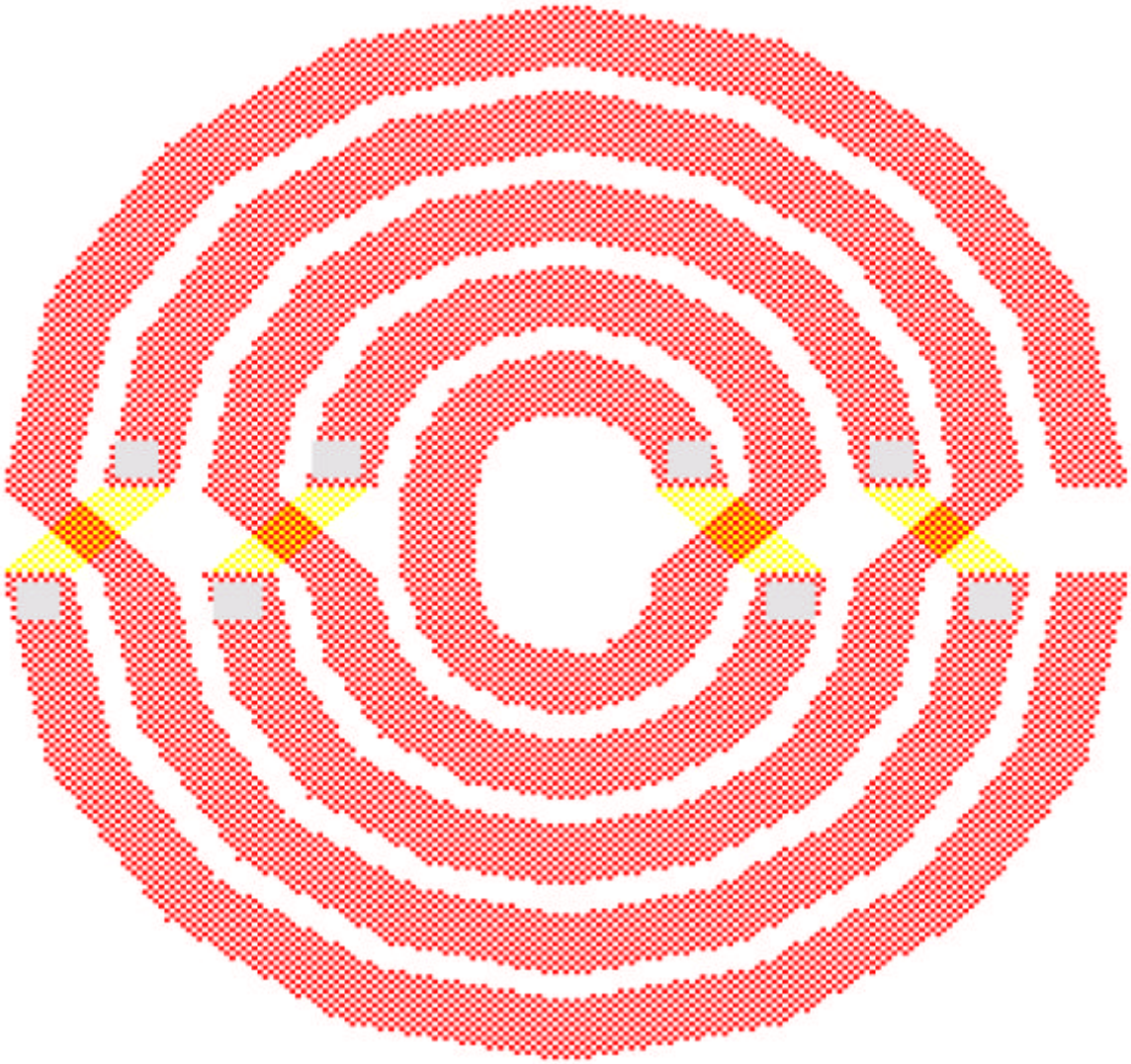




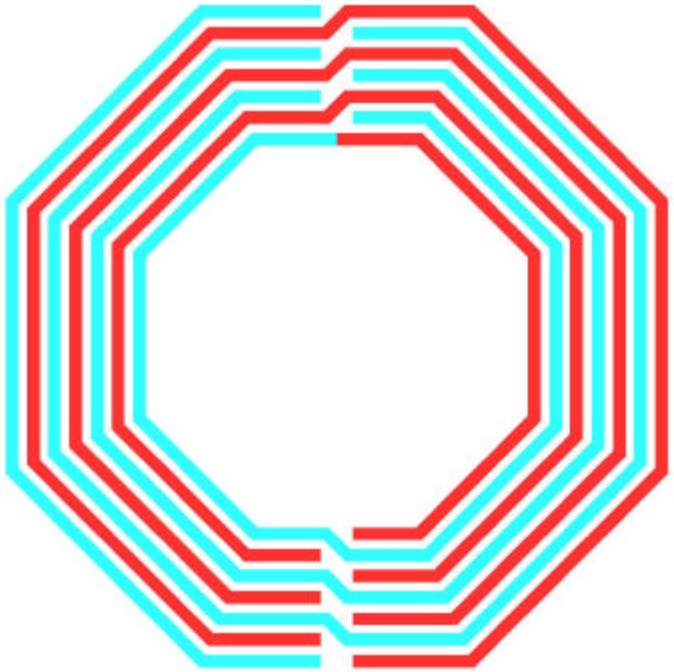
Differential Spiral

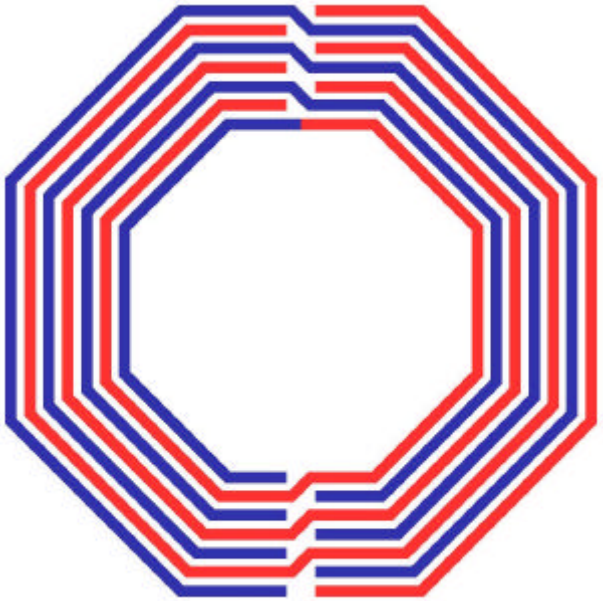


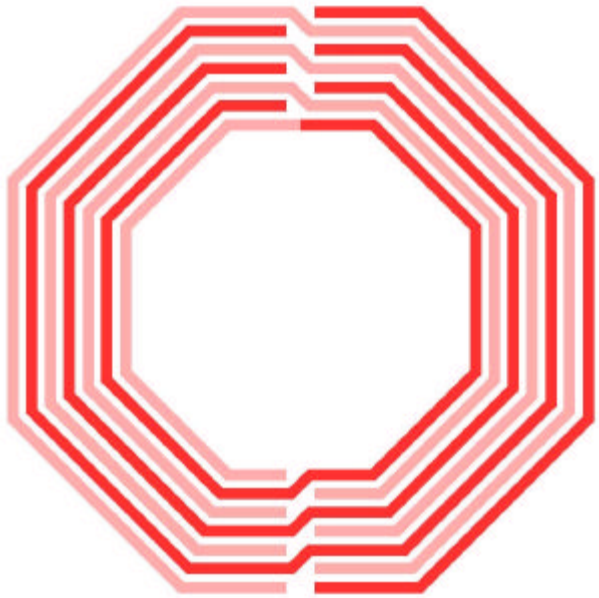
Balance Spiral



Stack Balance Spiral







More Inductor Lib?

- Shape: Square, Octagonal Inductor, Circular Inductor
- Single end or Balance Inductor

How to support customer's innovative inductor design?

- Provide measured inductor library.
- Provide scalable Pcell library.
- Why design engineer still need to struggle through design test structure, measure data and modeling than re_spin test structure, measure data then calibrate the model again,…….

UMC's innovative Approach

- In addition to existed tested, scalable library and model
- We provide extra ----
- An "methodology" that include process related information for EM software simulator, then customer can design innovative inductor with accuracy!
- Save prototype/test cycle time
- Reduce R&D cost

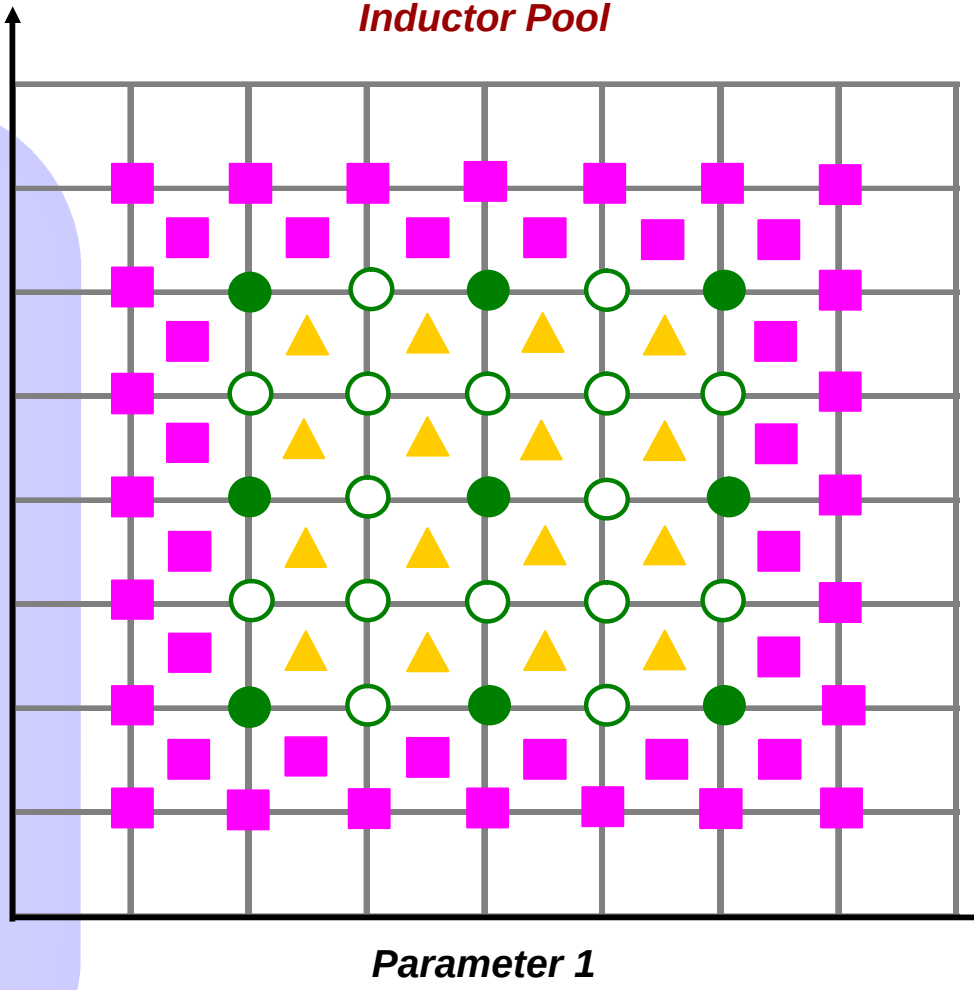
Ansoft HFSS

- Current Version 9.0
- A true 3D Electromagnetic-Based Design Tool
- Widely used in Package, Wave guide and Antenna
- UMC is the first Foundry that provide the methodology for using 3D EM design tool to support RFIC design

UMC's New Approach (1)
- What is Our Purpose?

- **General Inductor Design**

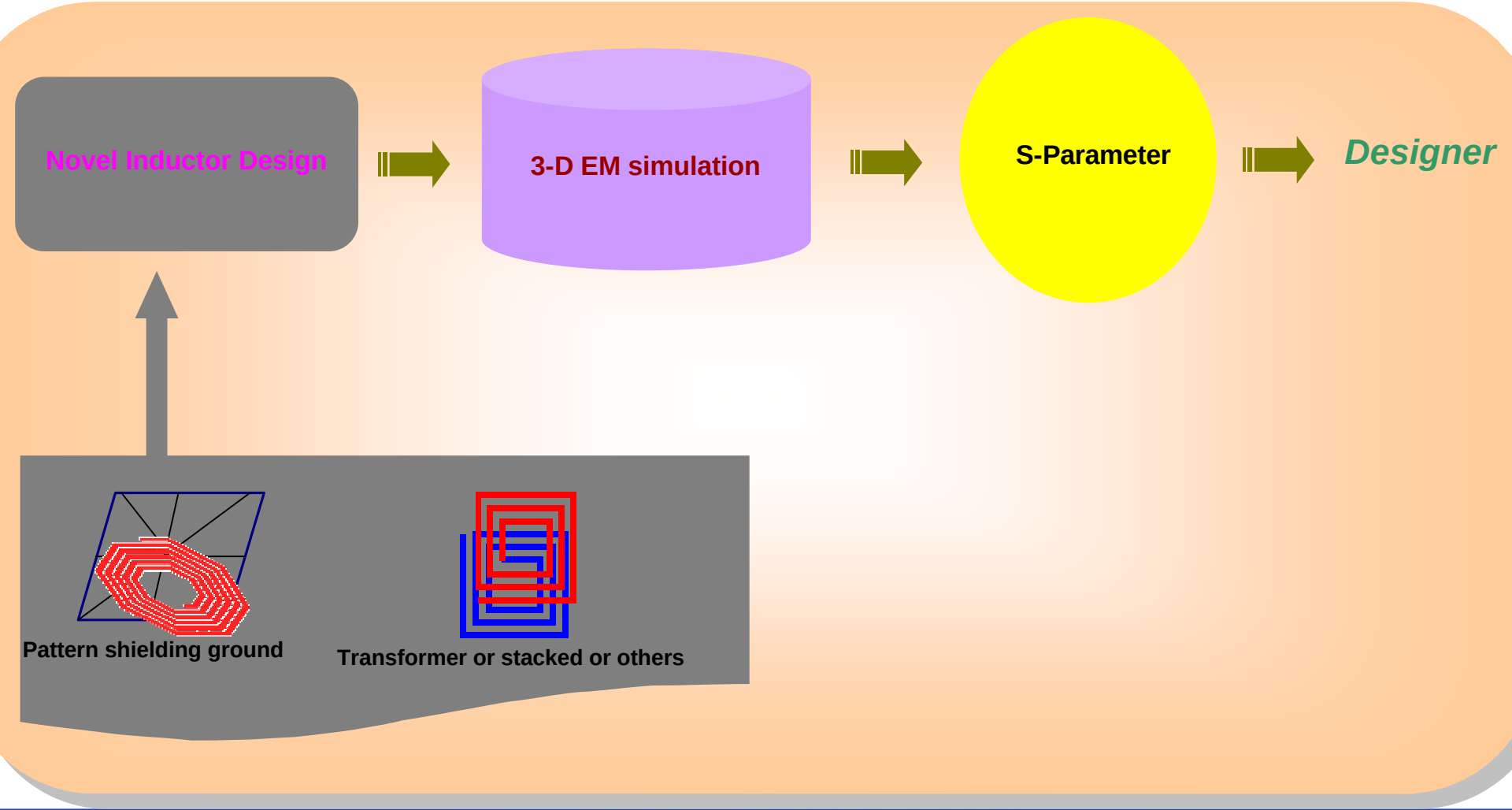
- With Si measurement data
- 3-D EM simulation data
- + ⟶ RF SPICE model
- 3-D EM simulation interpolation for S parameter
- 3-D EM simulation extrapolation for S parameter



Parameters : Xo; W; S & N

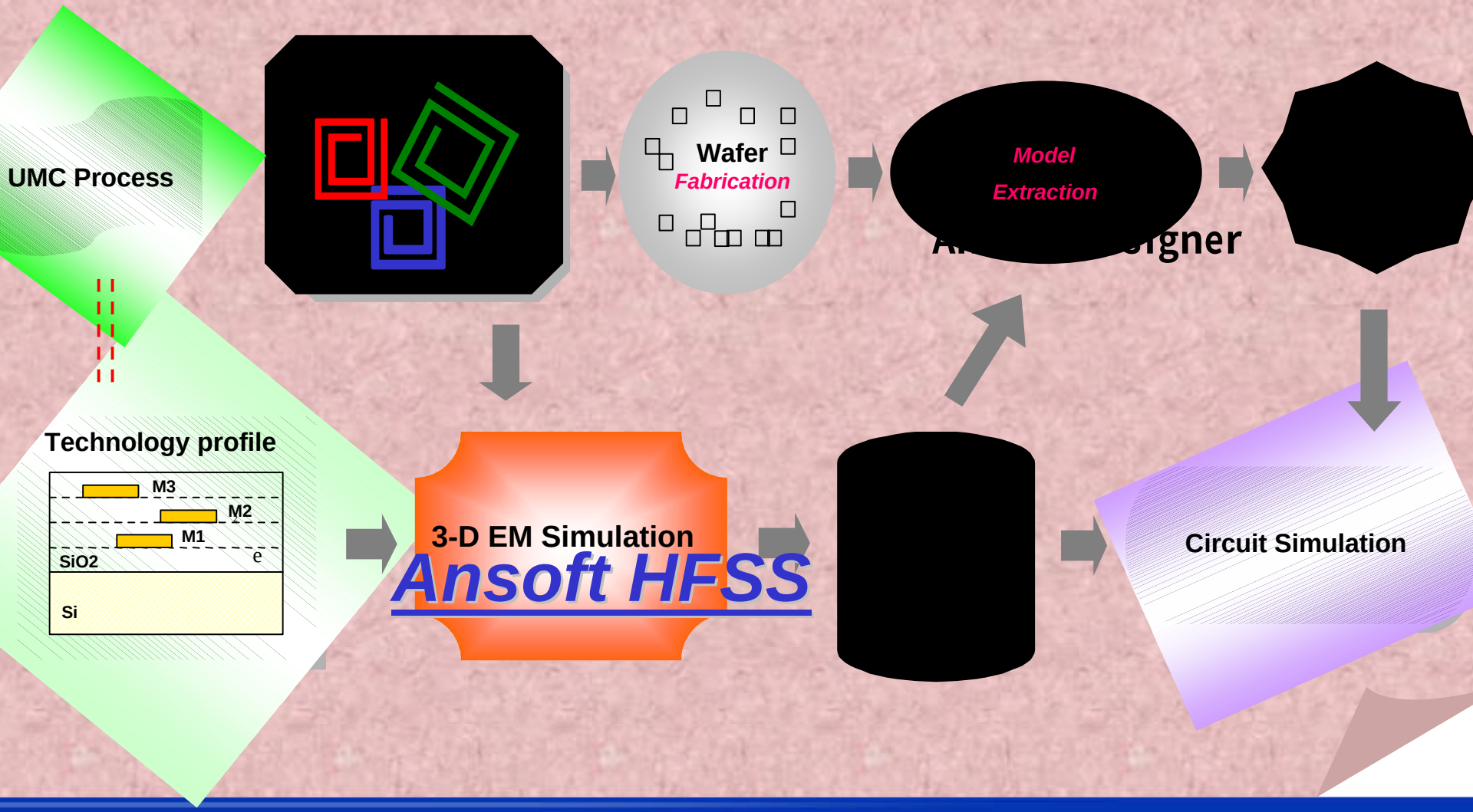
UMC's New Approach (2)
- What is Our Purpose?

- **Special Inductor Design**



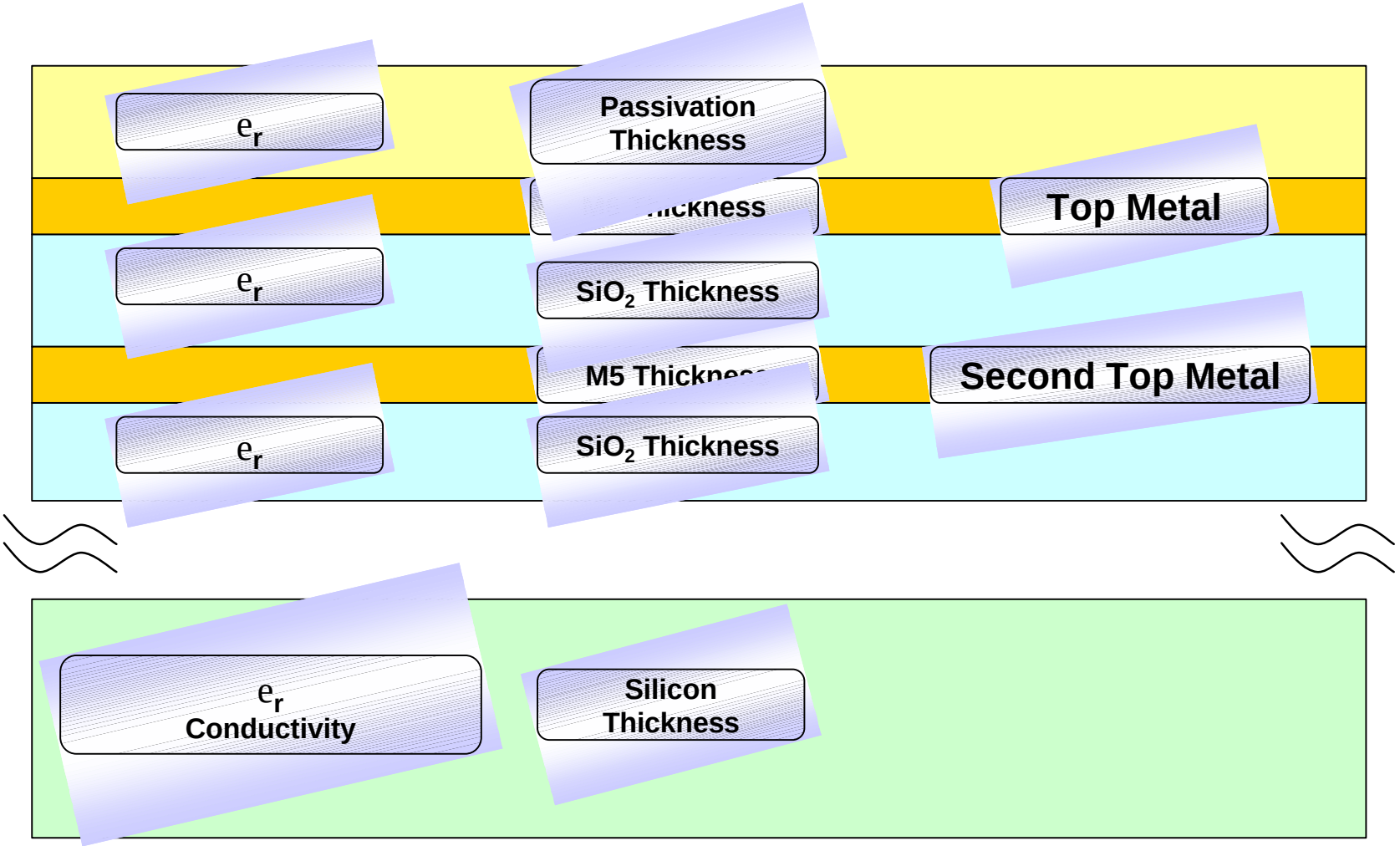
UMC's New Approach (3)

Work Flow



UMC's New Approach (4)

- What is Technology File?



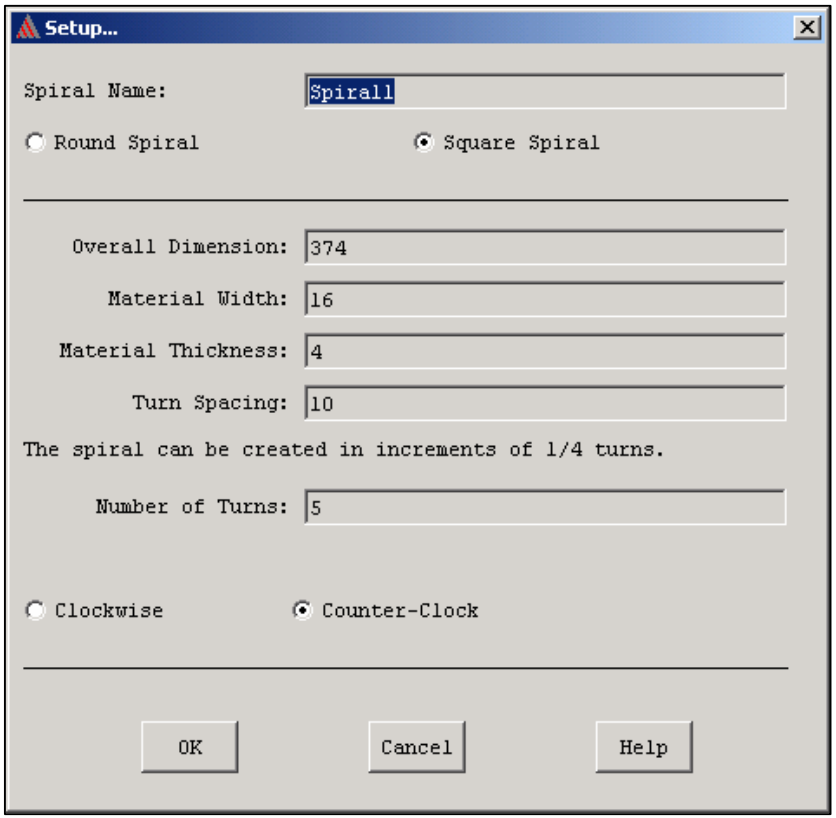
UMC's New Approach (5)

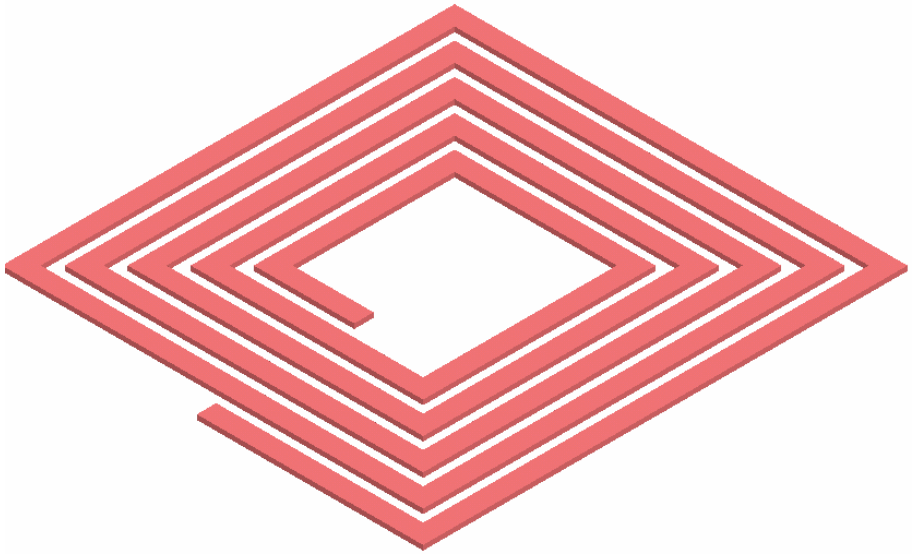
- What is Technology File?

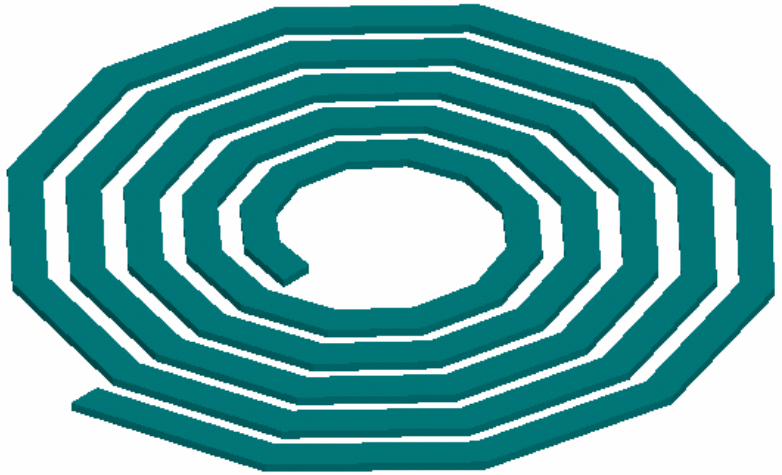
Material	Physic Param	Source
Substrate	T.K, Rs	EDR, SEM
STI	T.K, Dielectrics	EDR, SEM
M1~6	T.K, Rs	EDR, SEM
LD/IMD1~5	T.K, Dielectrics	EDR, SEM
Passivation	T.K, Dielectrics	EDR, SEM

Note: This unique technology file has been proved by comparing the simulation data with real Silicon measured data.

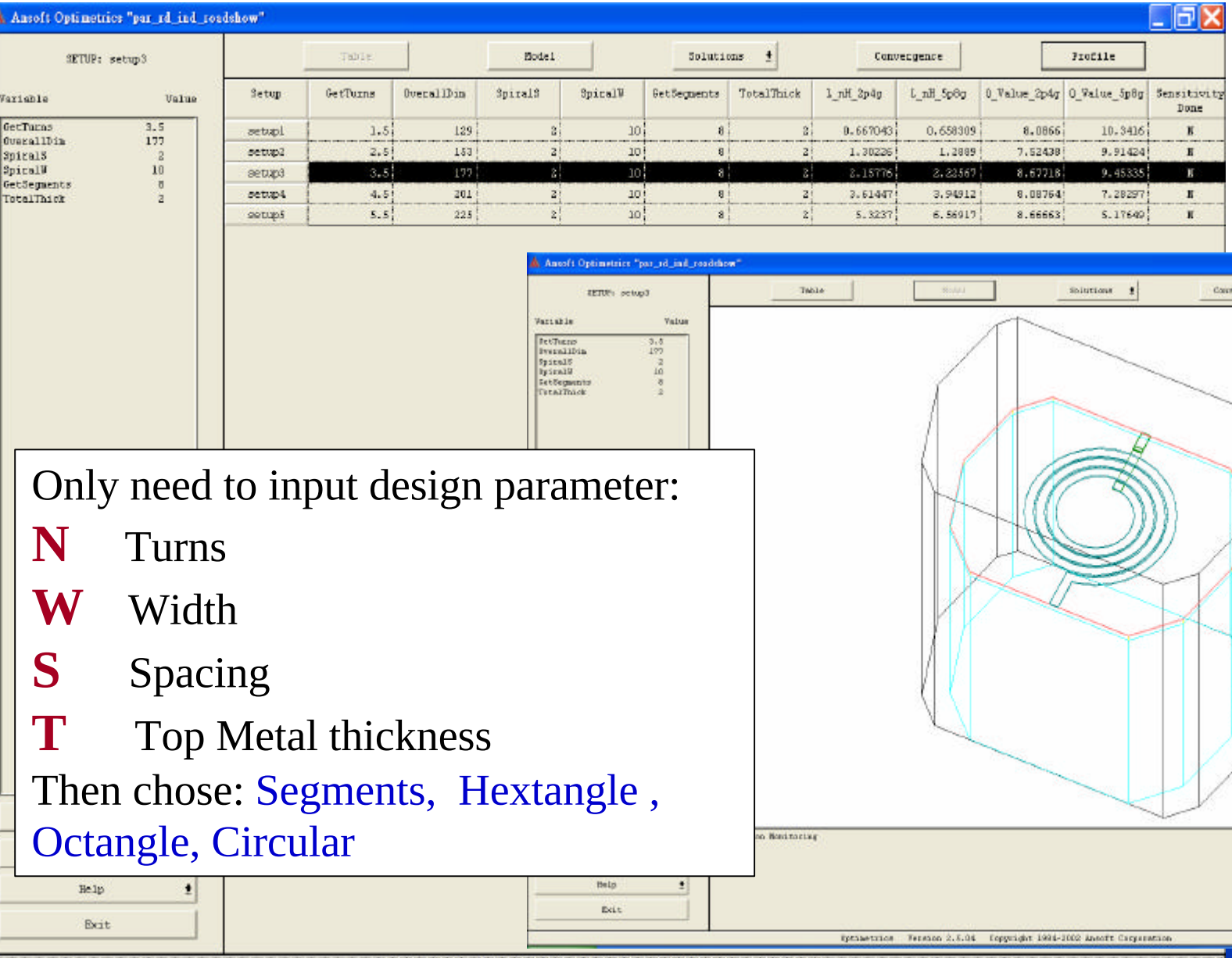
Ansoft HFSS: Spiral Inductor Macros







EMDM Inductor Design Flow



Only need to input design parameter:

N Turns

W Width

S Spacing

T Top Metal thickness

Then chose: Segments, Hextangle , Octangle, Circular

Operation Interface

GetTurns	OverallDim	SpiralS	SpiralW	GetSegments	TotalThick	L_nH_2p4g	L_nH_5p8g
1.5	150	2	10	8	2	0	0
1.5	150	2	15	8	2	0	0
1.5	160	2	10	8	2	0	0
1.5	160	2	15	8	2	0	0
2.5	150	2	10	8	2	0	0
2.5	150	2	15	8	2	0	0
2.5	160	2	10	8	2	0	0
2.5	160	2	15	8	2	0	0
3.5	150	2	10	8	2	0	0
3.5	150	2	15	8	2	0	0
3.5	160	2	10	8	2	0	0
3.5	160	2	15	8	2	0	0
4.5	150	2	10	8	2	0	0
4.5	150	2	15	8	2	0	0
4.5	160	2	10	8	2	0	0
4.5	160	2	15	8	2	0	0

- **It is friendly to user that just only key in inductor's parameter;Overall Dimension, Width, Spacing, Turns & Thickness**

Current Status

- Success develop an unique technology file to represent UMC's process used in Ansoft HFSS EM simulation.
- Process: 0.18um Logic 1P6M process with 20KA and 30kA Al top thick Metal.
- Valid Frequency Range: Simulation & Measurement sweep frequency: 0.6GHz~20.6GHz

Current Status

- For general Inductor design, both real Silicon measurement data and 3-D simulation data are used in the model extraction.
- Combining these two groups of raw data, we can extract RF SPICE model with higher accuracy.
- The technology file used in here can be faithfully represents Silicon process parameter.
- Based on the calibrated technology file, designers can implement novel idea, then obtain S-parameter for circuit simulation.

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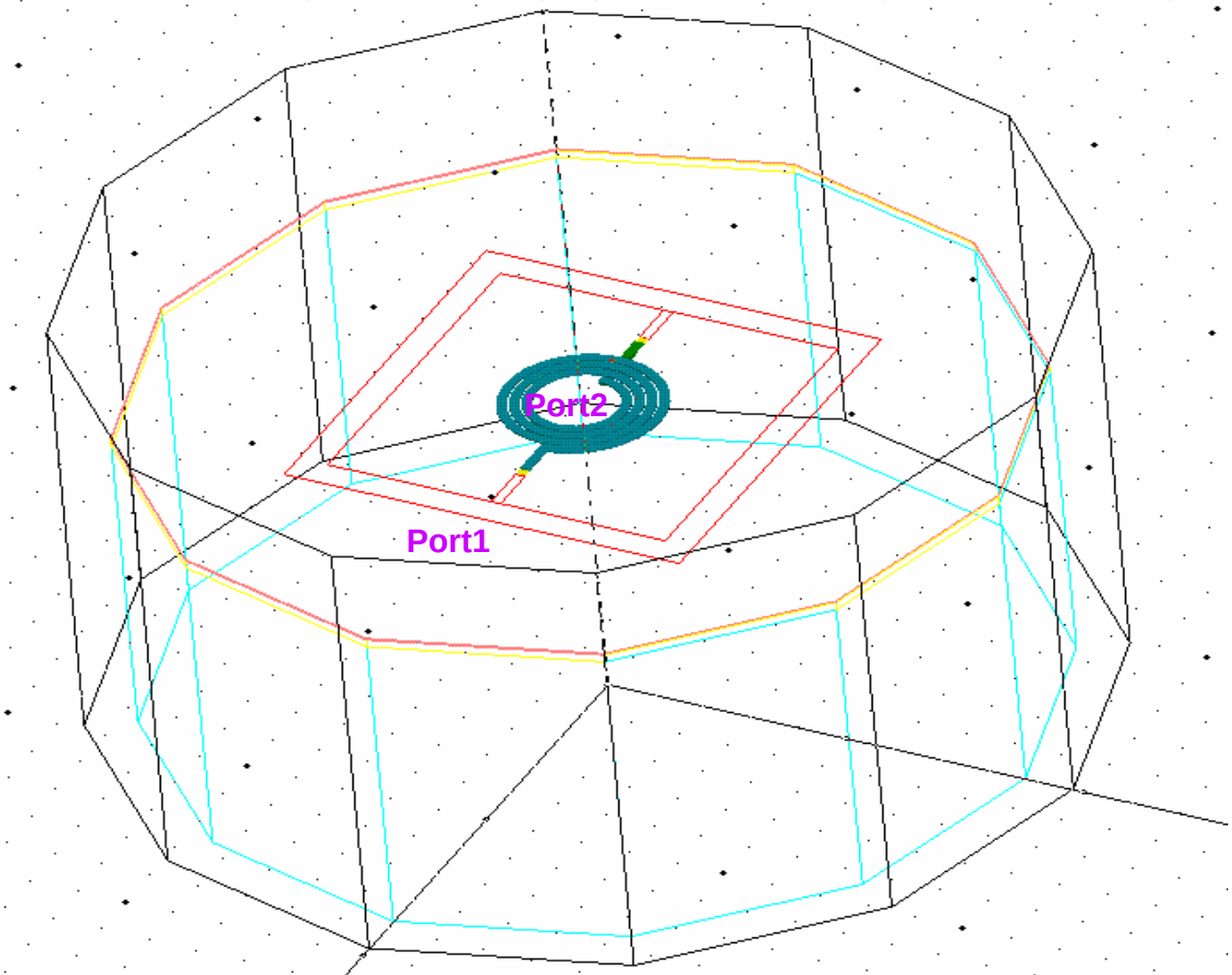
Results and Discussion (1)
- Device Sampling

- **Group1=>**
  - **Scale Number of Turns**
- **Group2=>**
  - **Scale Inner Diameter**

W(um)	S(um)	Turns	Inner-Diameter(um)	Thickness(KA)
6	2	1.5	126	20
"	"	"	"	"
6	2	1.5	238	20
"	"	"	"	"
10	2	1.5	85	20
"	"	"	"	"
"	"	"	"	"
10	2	2.5	85	20
"	"	"	"	"
10	2	3.5	85	20
"	"	"	"	"
10	2	4.5	85	20
"	"	"	"	"
10	2	5.5	85	20
"	"	"	"	"
"	"	"	"	"
15	2	3.5	85	20
"	"	"	"	"
15	2	3.5	150	20
"	"	"	"	"
15	2	3.5	230	20
"	"	"	"	"
"	"	"	"	"
20	2	4.5	236	20
20	2	5.5	236	20

Results and Discussion (2)

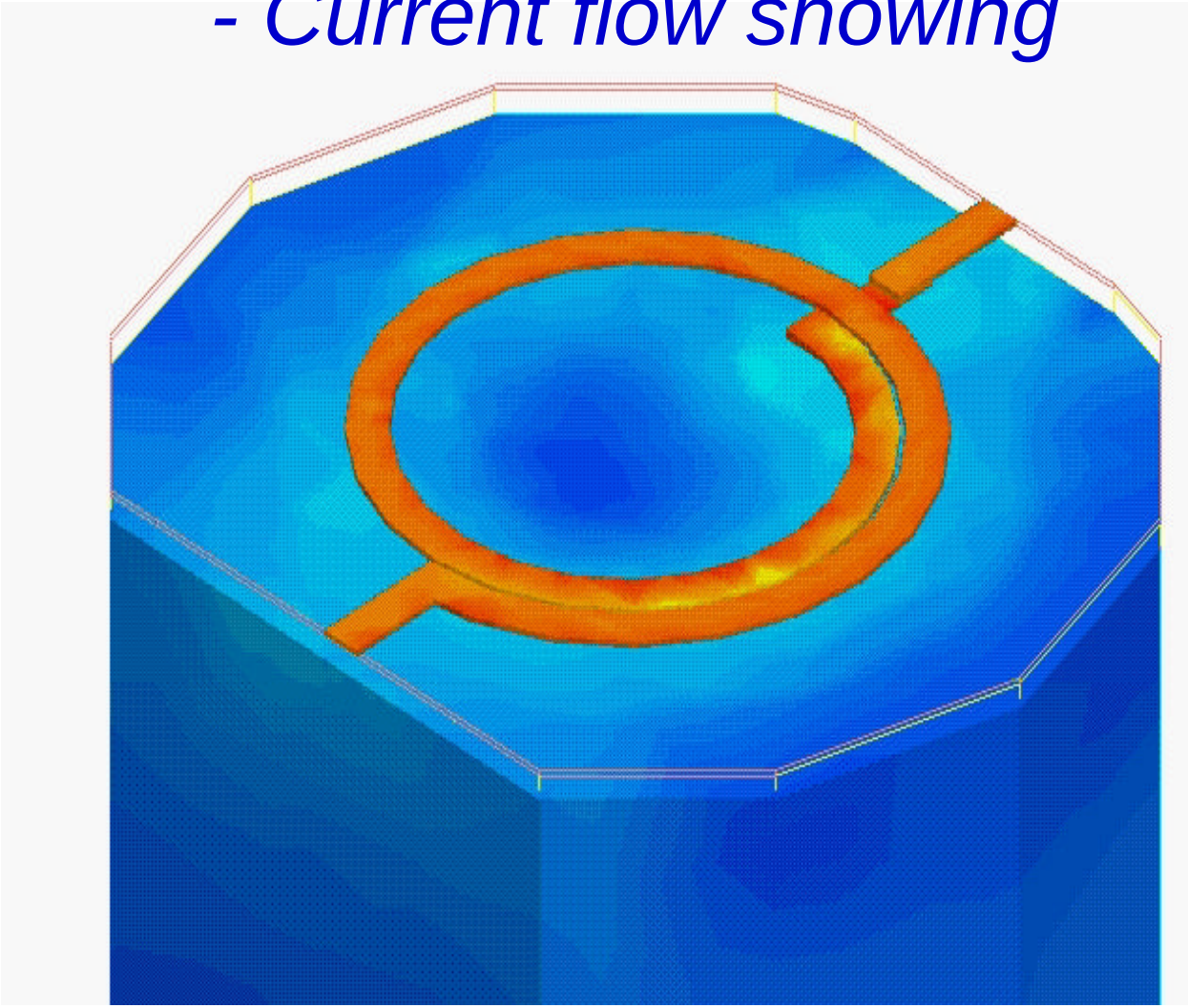
- Inductor Simulation Profile



- 3-D design environment, substrate effect can be included.

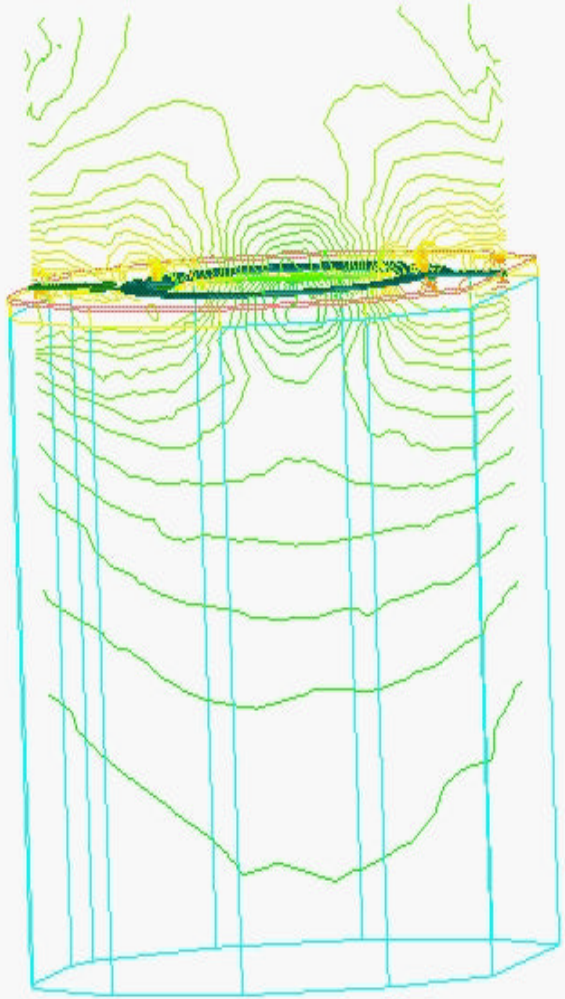
Results and Discussion (3)

- Current flow showing

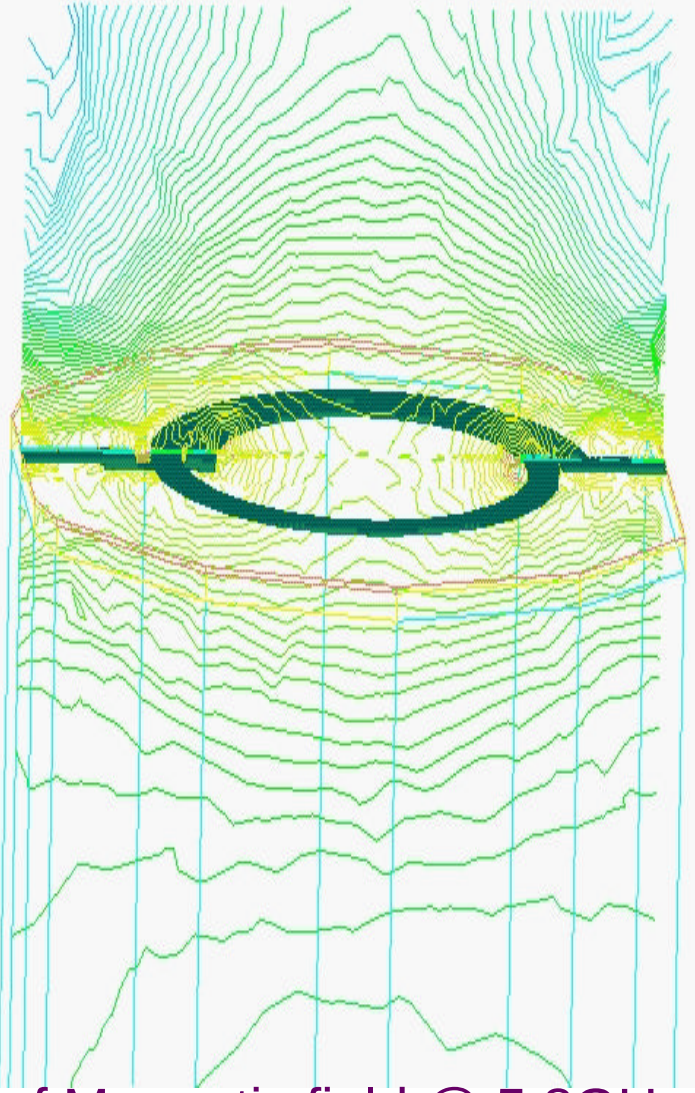


- Current flow @ 5.8GHz

Results and Discussion (4)
- E&M field showing



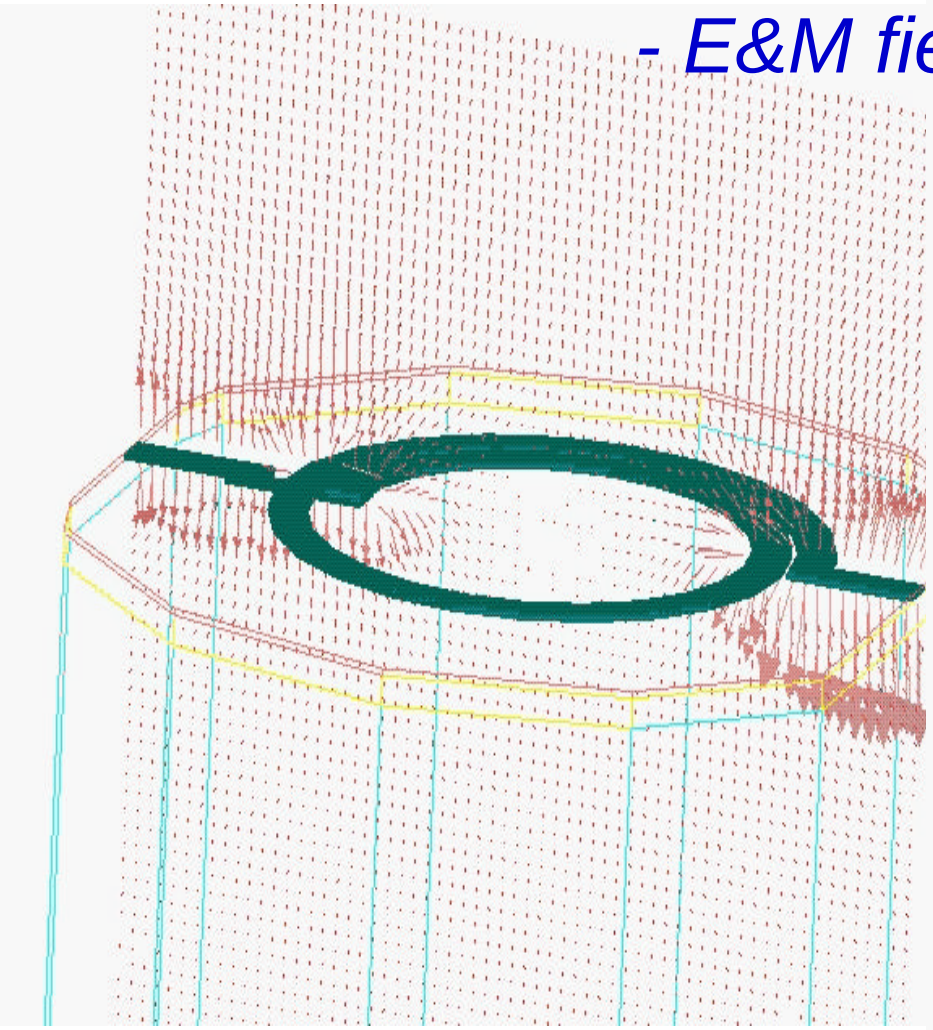
Mag of Electric field @ 5.8GHz



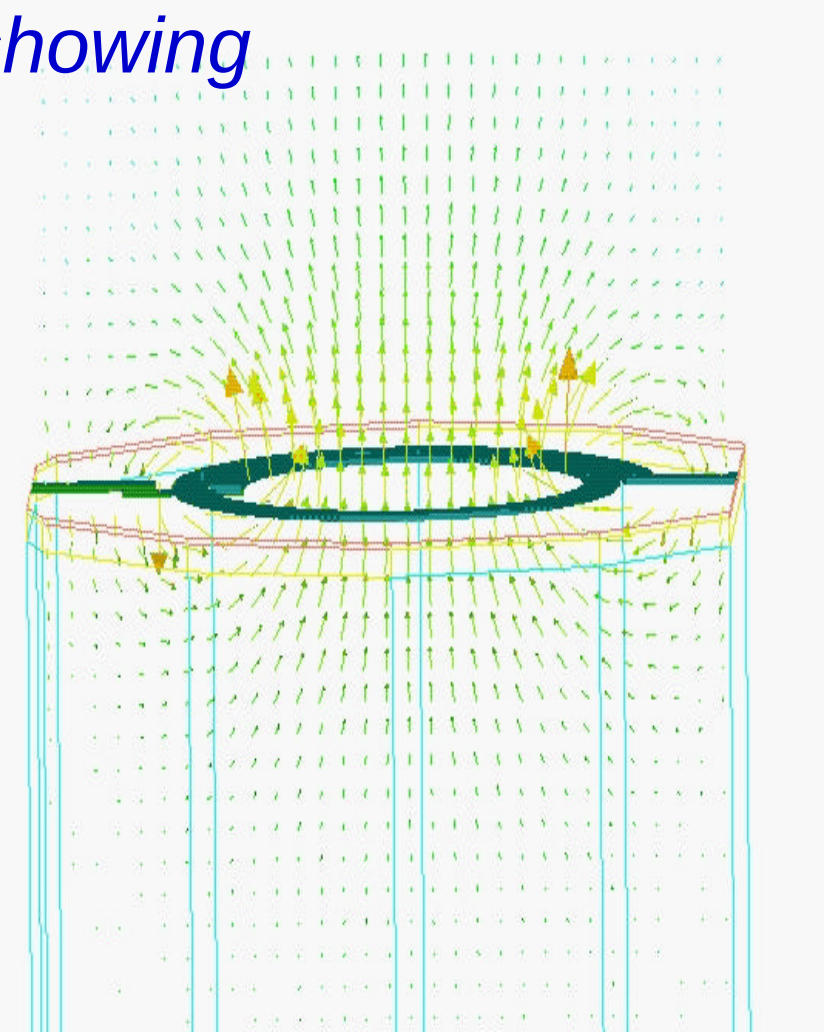
Mag of Magnetic field @ 5.8GHz

Results and Discussion (5)

- E&M field showing

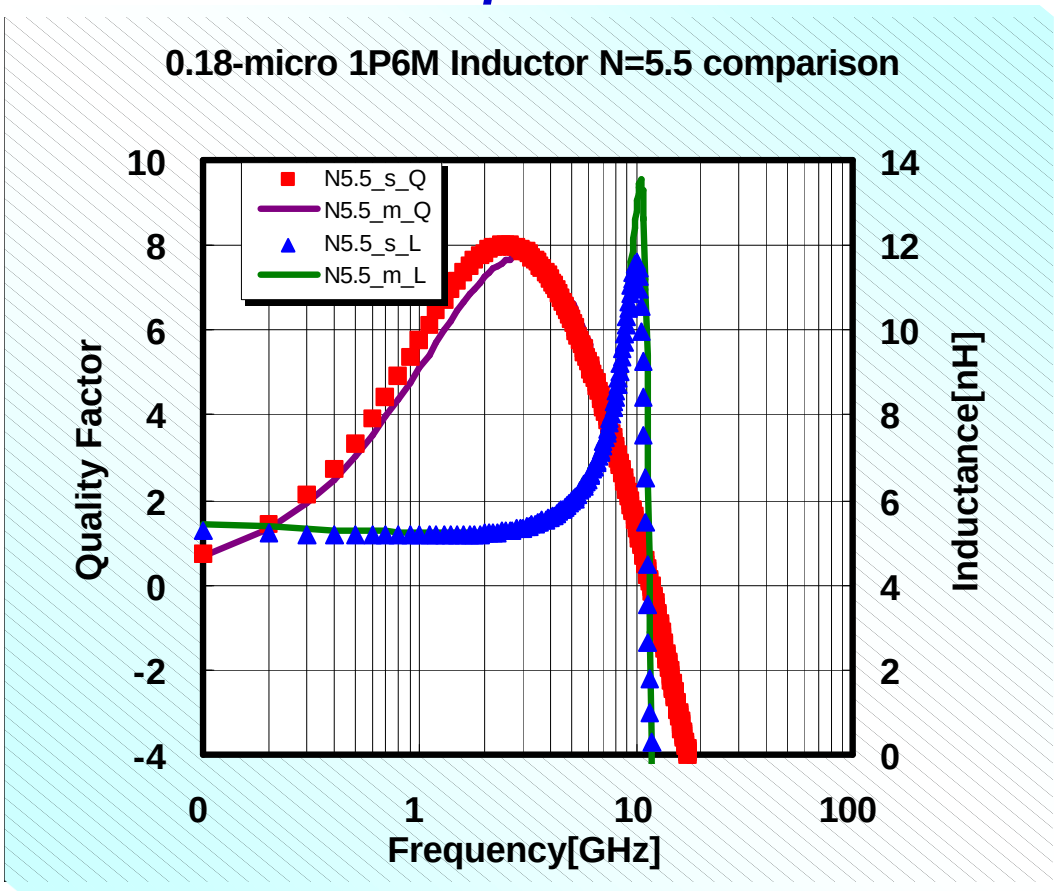


Vector of Electric field @ 5.8GHz



Vector of Magnetic field @ 5.8GHz

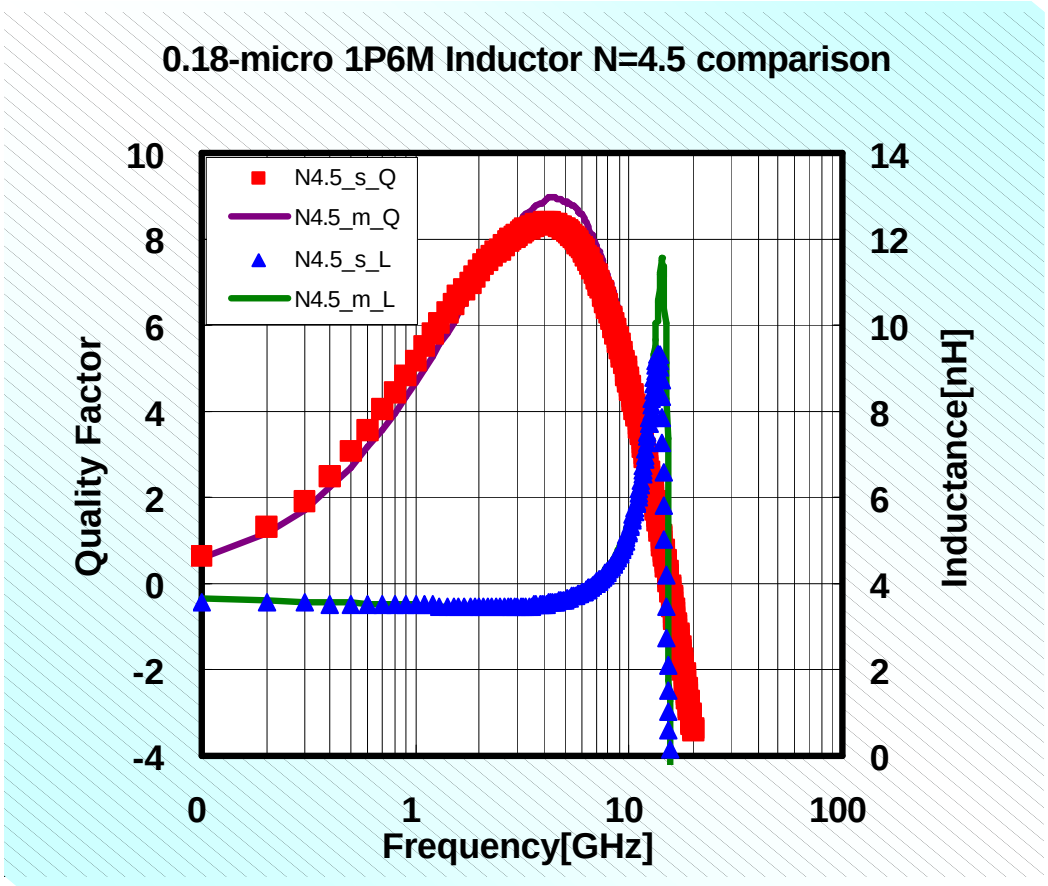
Results and Discussion (6)
- L/Q simulation&measurement comparison



- **Width=10μm, Spacing=2μm, Di= 85μm, Turns=5.5, Al=20KA**

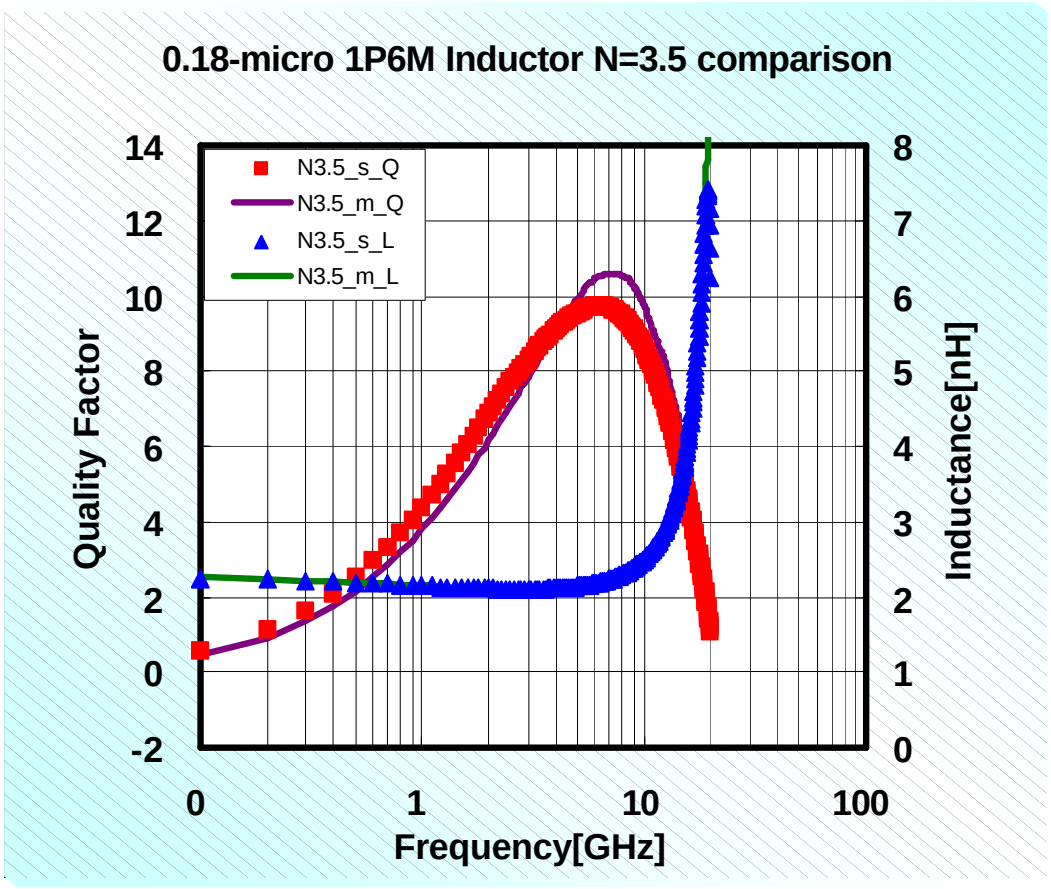
Results and Discussion (7)

- L/Q comparison



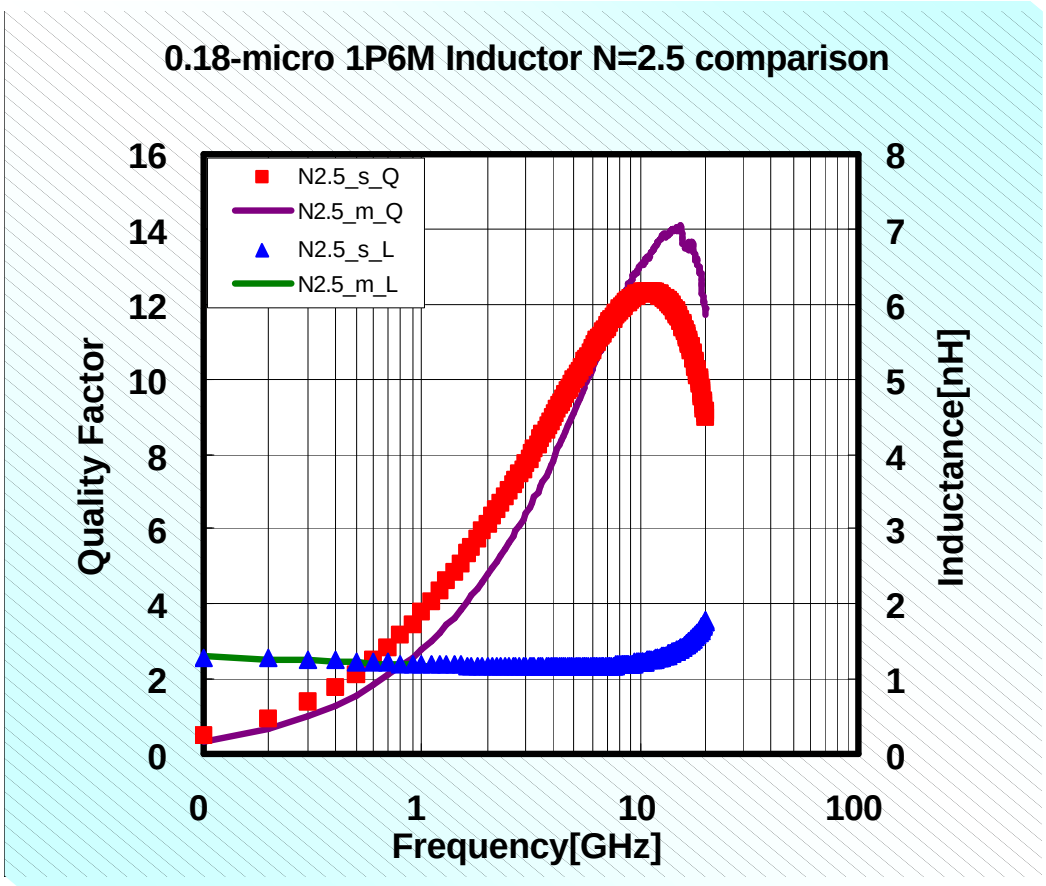
- Width=10μm, Spacing=2μm, Di= 85μm, Turns=4.5, Al=20KA

Results and Discussion (8)
- L/Q comparison



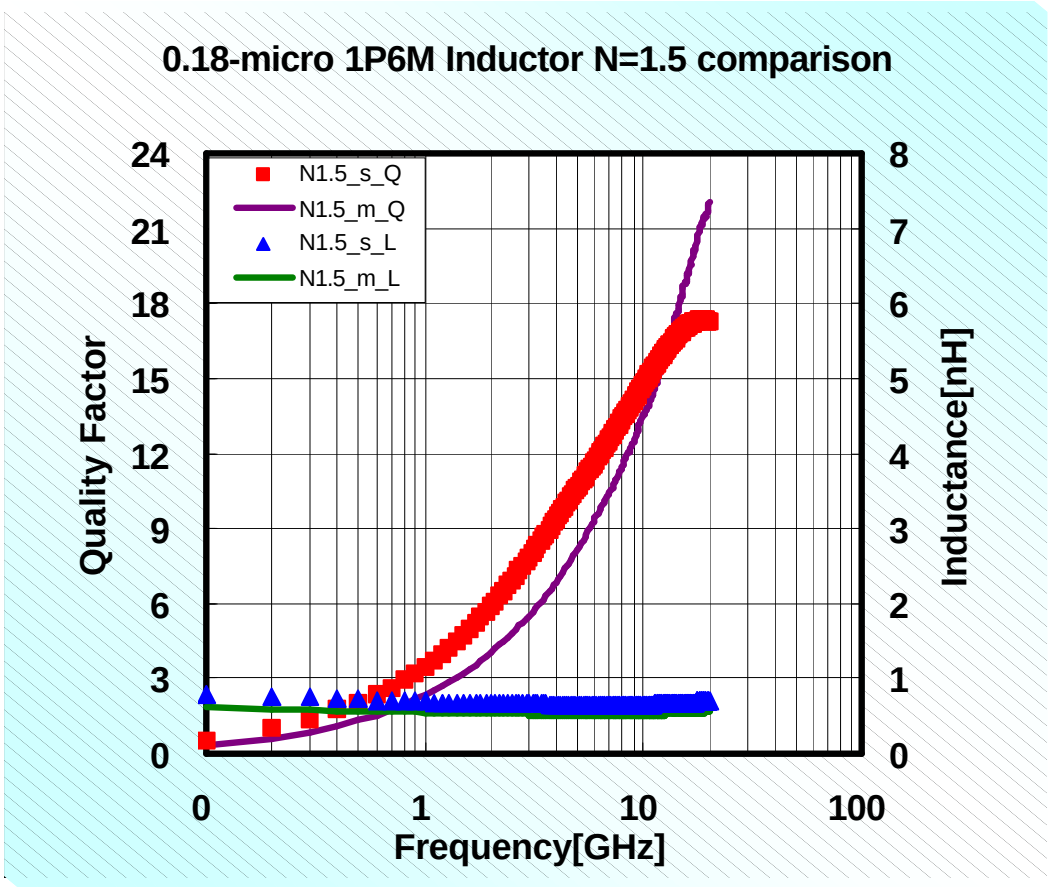
- Width=10μm, Spacing=2μm, Di= 85μm, Turns=3.5, Al=20KA

Results and Discussion (9)
- L/Q comparison



- Width=10μm, Spacing=2μm, Di= 85μm, Turns=2.5, Al=20KA

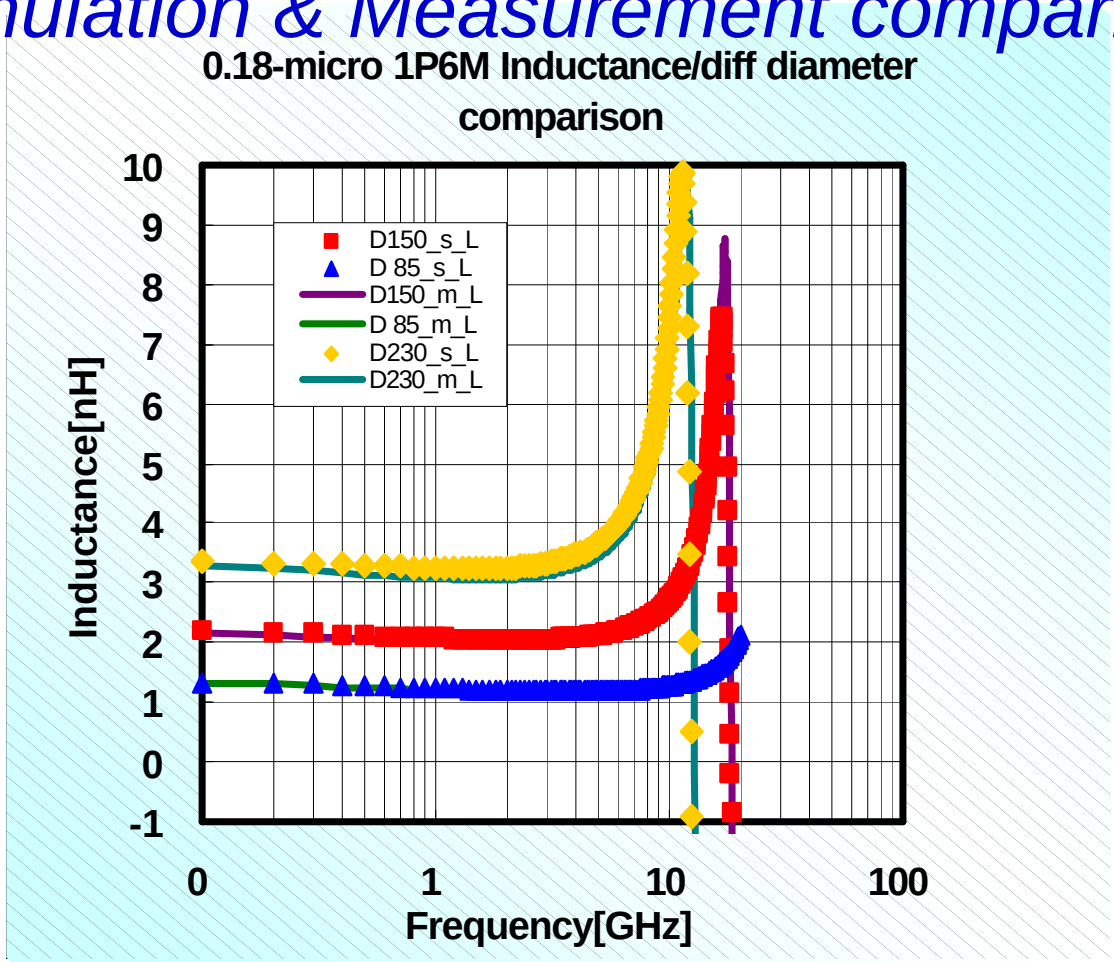
Results and Discussion (10)
- L/Q comparison



- Width=10μm, Spacing=2μm, Di= 85μm, Turns=1.5, Al=20KA

Results and Discussion (11)

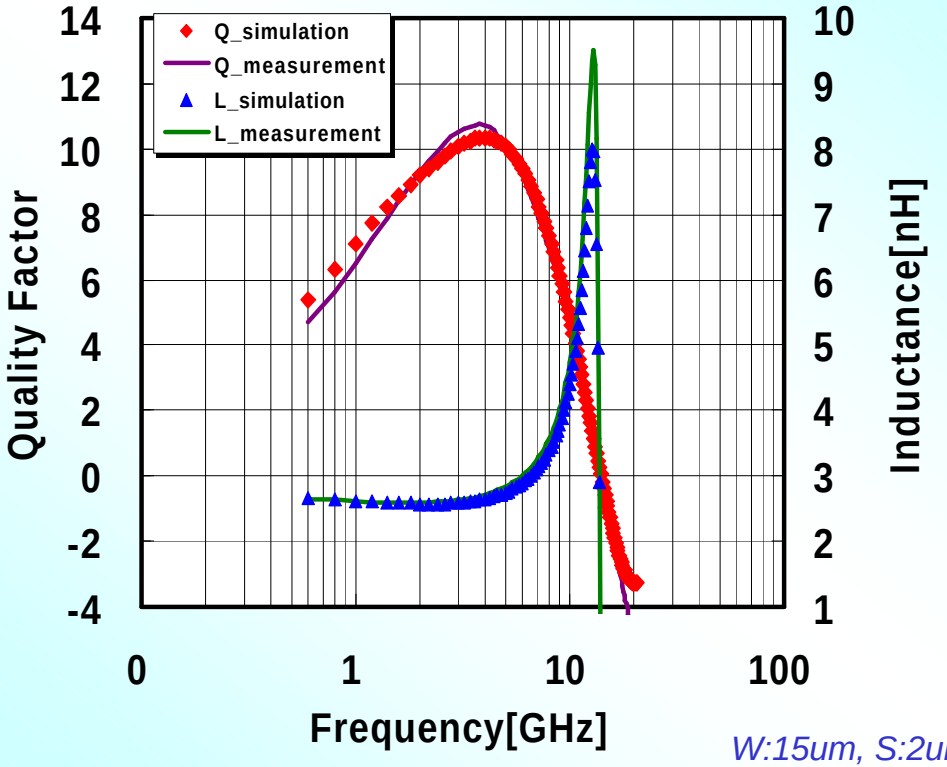
- Simulation & Measurement comparison



- Fixed width=15μm, spacing=2μm, Turns=2.5 & AI=20KA, variable Di: 85μm, 150μm and 230μm
- Good agreement with inductance.

Results and Discussion (12)

- Inductance & Q-value Comparison - (Case1)

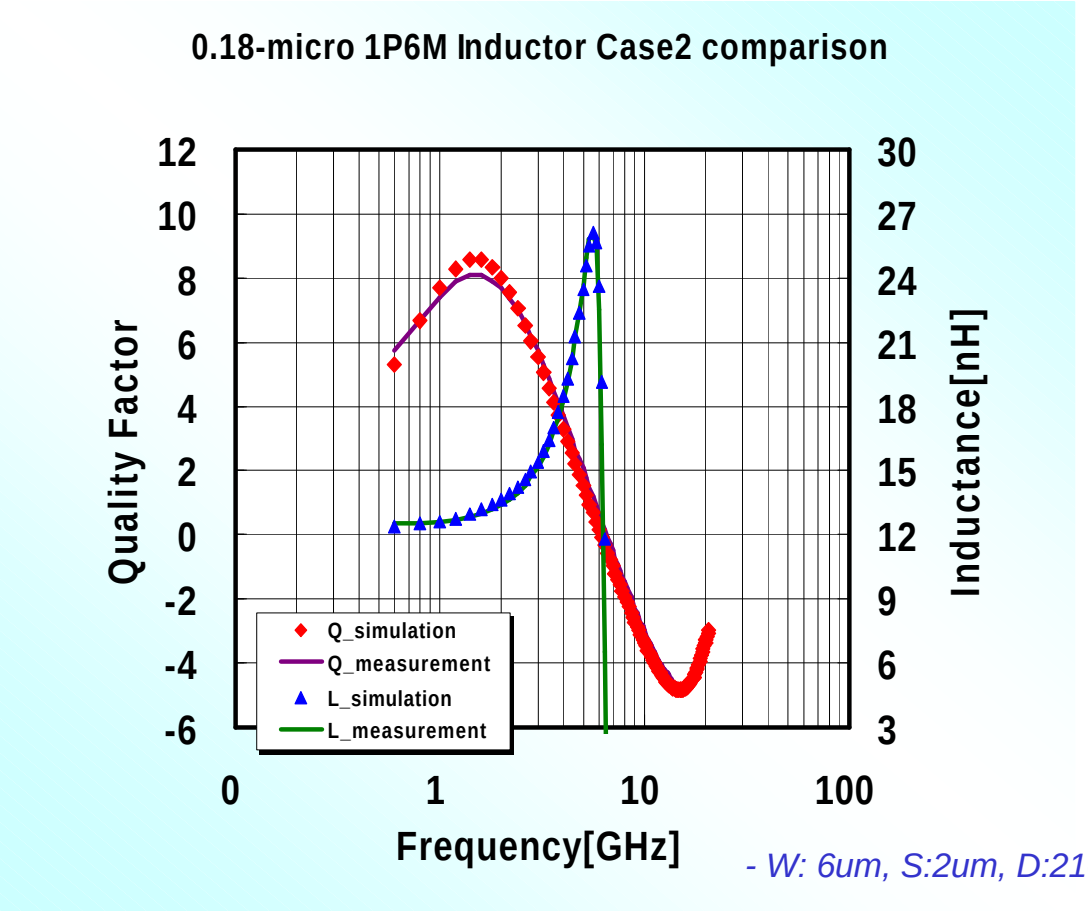


W:15um, S:2um, D:202um, N:2p5, AL:30K

- **Simulation: Qmax = 10.35 @ 4GHz, Fsr=14.2GHz.**
- **Measurement: Qmax = 10.8 @ 3.8GHz, Fsr=14GHz.**

Results and Discussion (13)

- Inductance & Q-value Comparison (Case2)



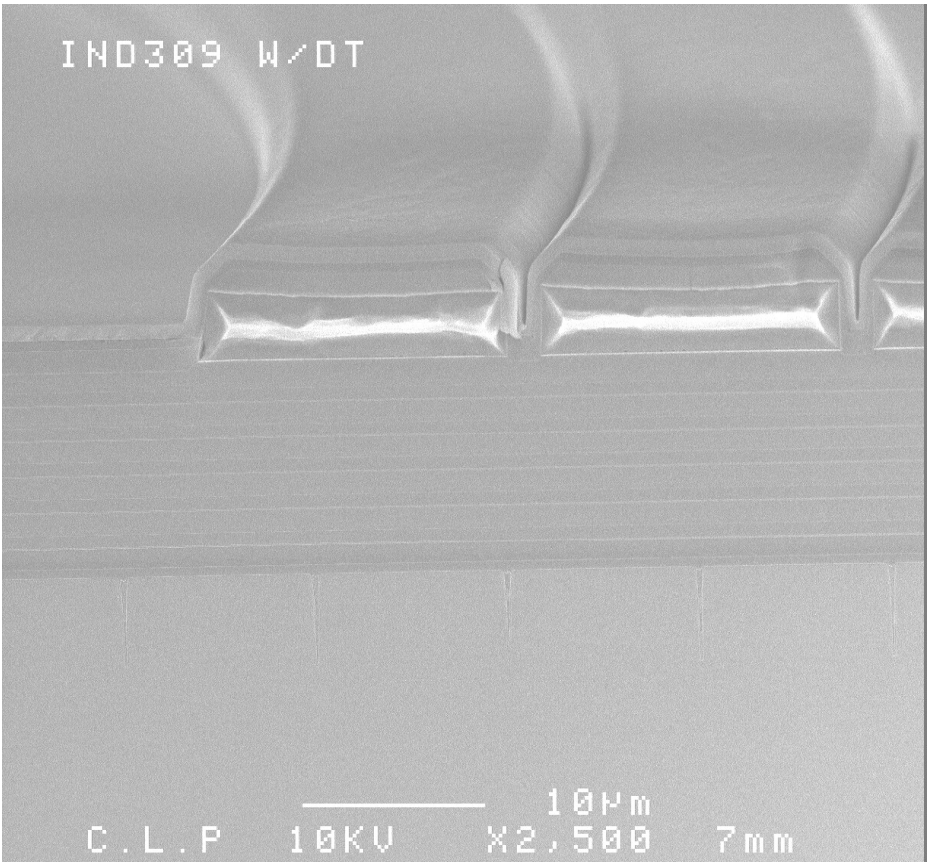
- W: 6um, S:2um, D:210um, N:5p5, AL:30K

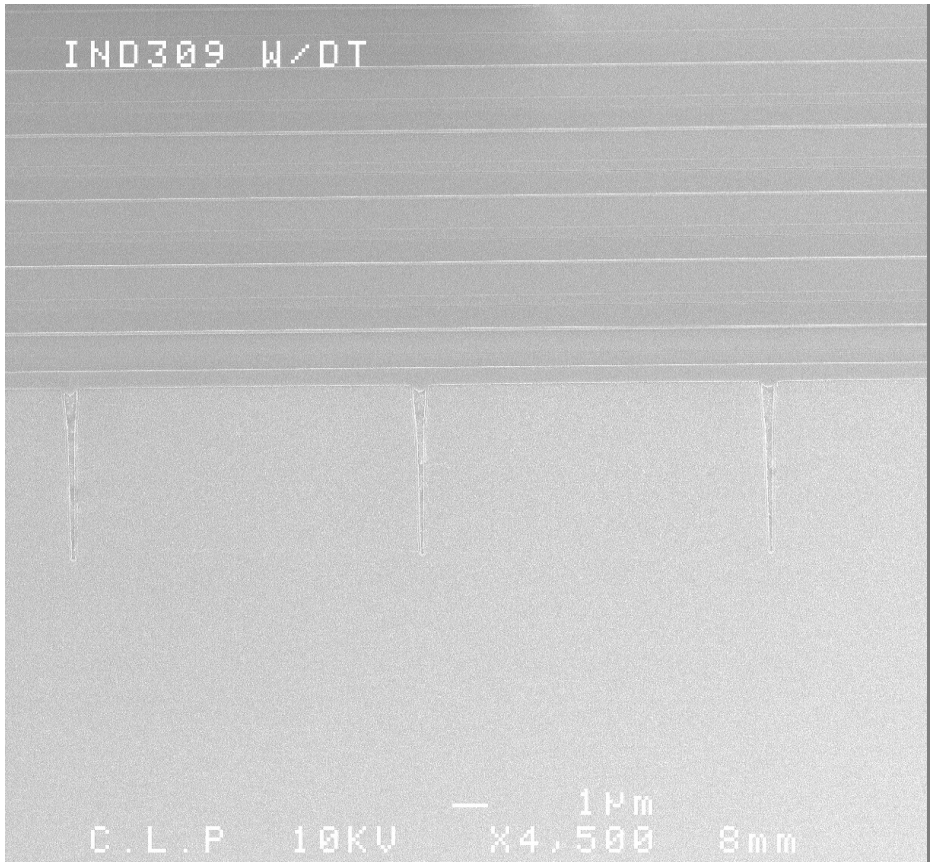
- **Simulation: Qmax = 8.57 @ 1.4GHz, Fsr=6.2GHz.**
- **Measurement: Qmax = 8.1 @ 1.4GHz, Fsr=6.4GHz.**

Results and Discussion (14)

- Deep-trench pattern--case3

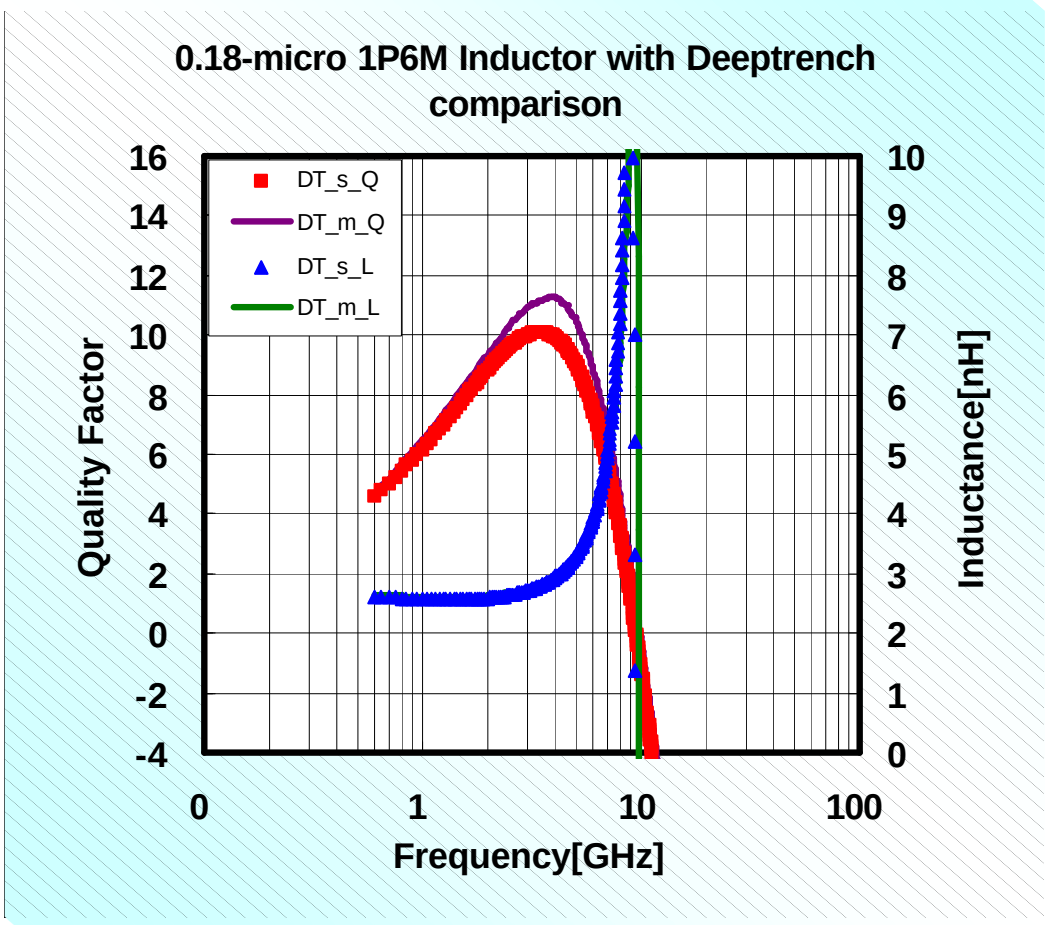
- Use Deep-trench to reduce substrate loss.
- Deep-trench Side Cross Section.





Results and Discussion (15)

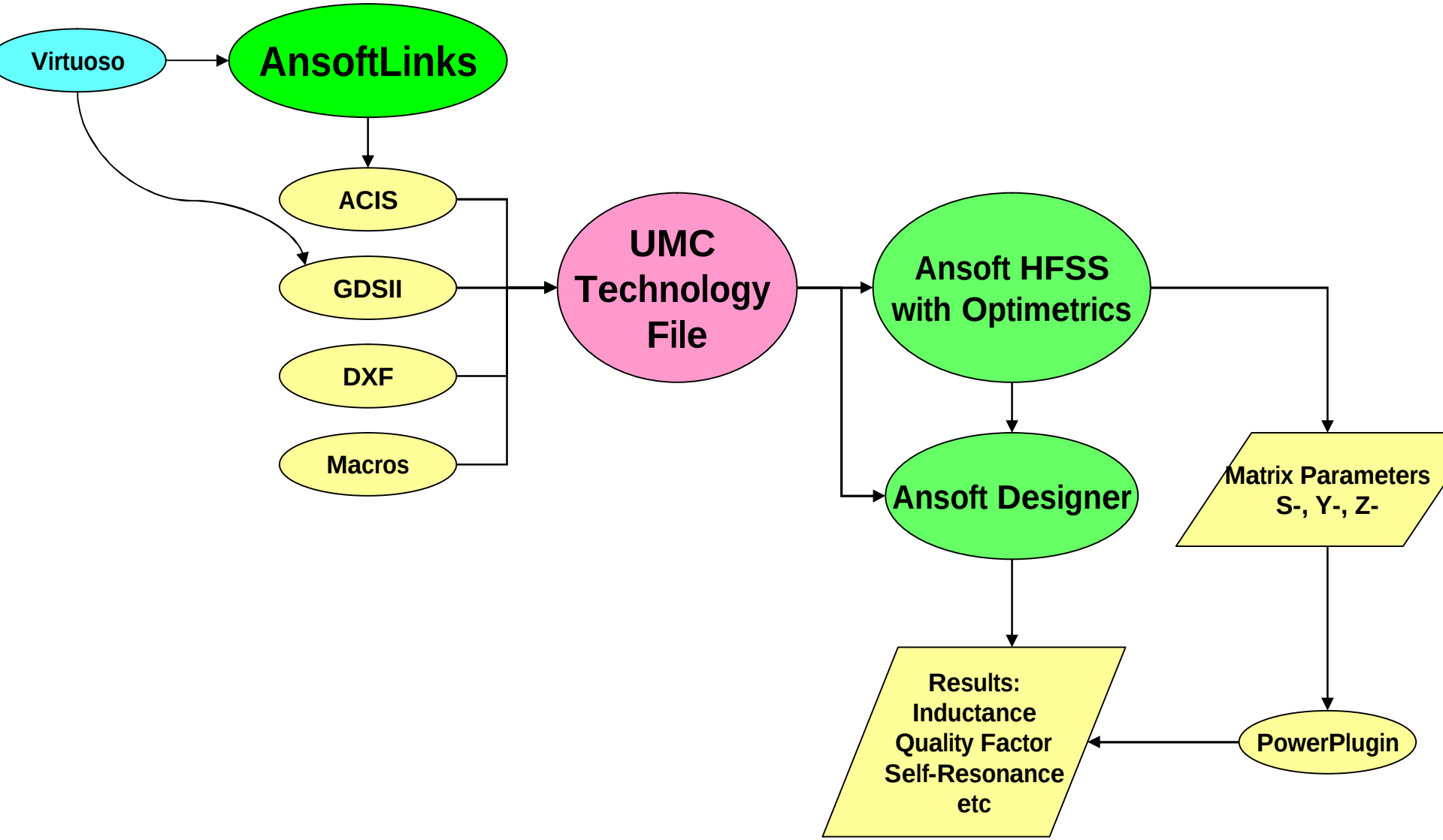
- Deep-trench pattern--case3



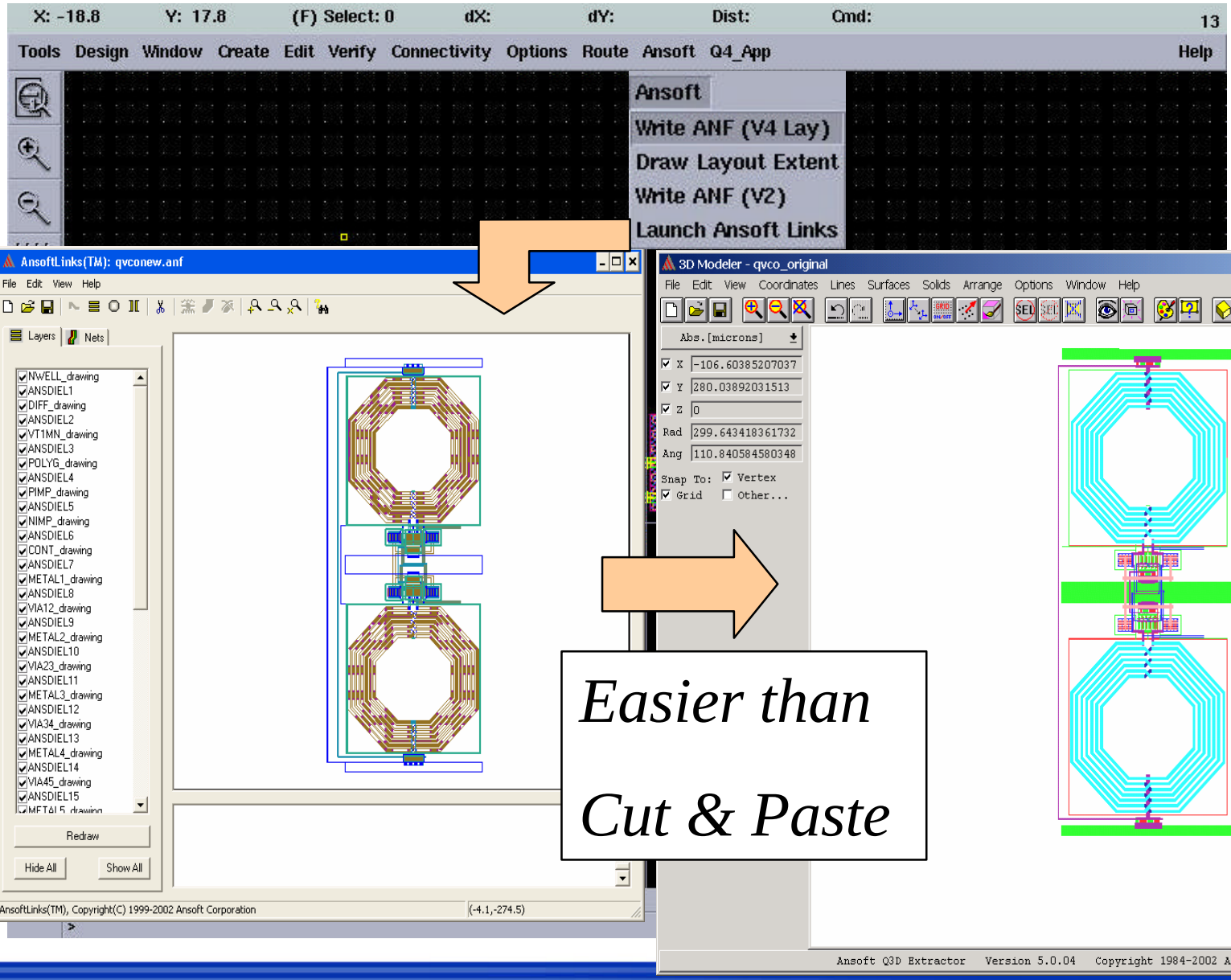
Outline

- Introduction
- Inductor Library from Foundry
- Customer Request on Inductor
- Inductor Design Methodology {EMDM}
- Results and Comparison
- Other Application using EMDM
- Conclusion

EMDM Flow


Virtuoso
AnsoftLinks
ACIS
GDSII
DXF
Macros
UMC Technology File
Ansoft HFSS with Optimetrics
Ansoft Designer
Matrix Parameters S-, Y-, Z-
Results: Inductance Quality Factor Self-Resonance etc
PowerPlugin

AnsoftLink for Virtuoso



Easier than

Cut & Paste

Other Use of HFSS in IC design

- With UMC EMDM:
  - Model extraction on Interconnection
  - Cross Talk analysis in RF or High Speed Digital IC
  - Capacitor: MIM, MOM (fringing)
  - Package Modeling for the IC Design
  - Internal Antenna Design
  - EM analysis RFIC with PCB

Outline

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Conclusion

- Customer’s success is always our first goal
- The RF design support is enhanced by providing an accurate, efficient methodology for inductor library development.
- EMDM can be extended to use in much general high frequency analysis base on the same unique tech file.
- Reduce develop cycle time and cost, customer can go into production much faster.
- UMC is always seeking a better, improved service for our customer

Please Fill Out the Survey Questionnaires