

THE WORLD'S NO. 1 INDEPENDENT FOUNDRY

*New Methodology for Spiral
Inductor Design*

Albert Yen

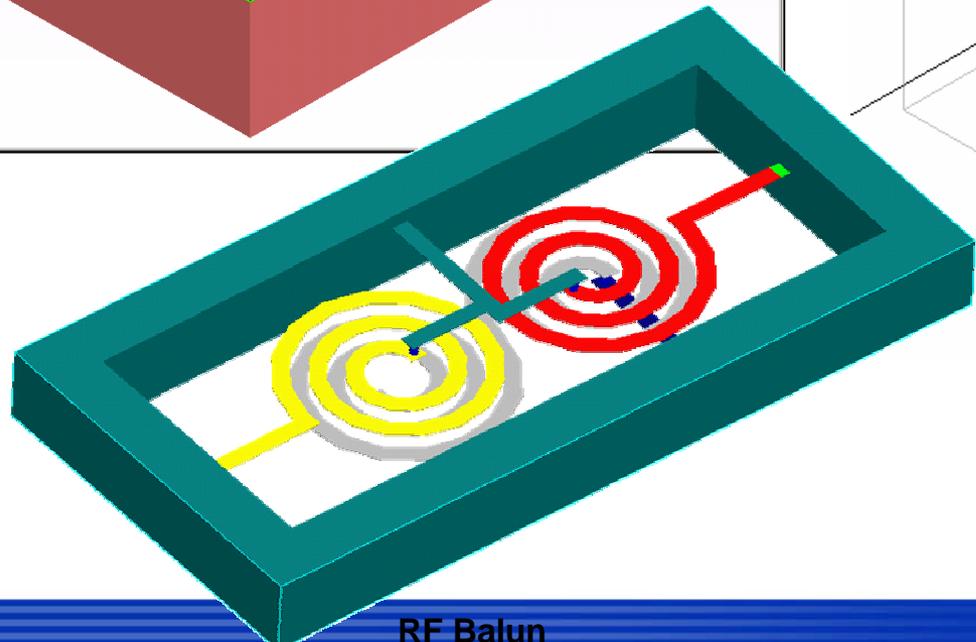
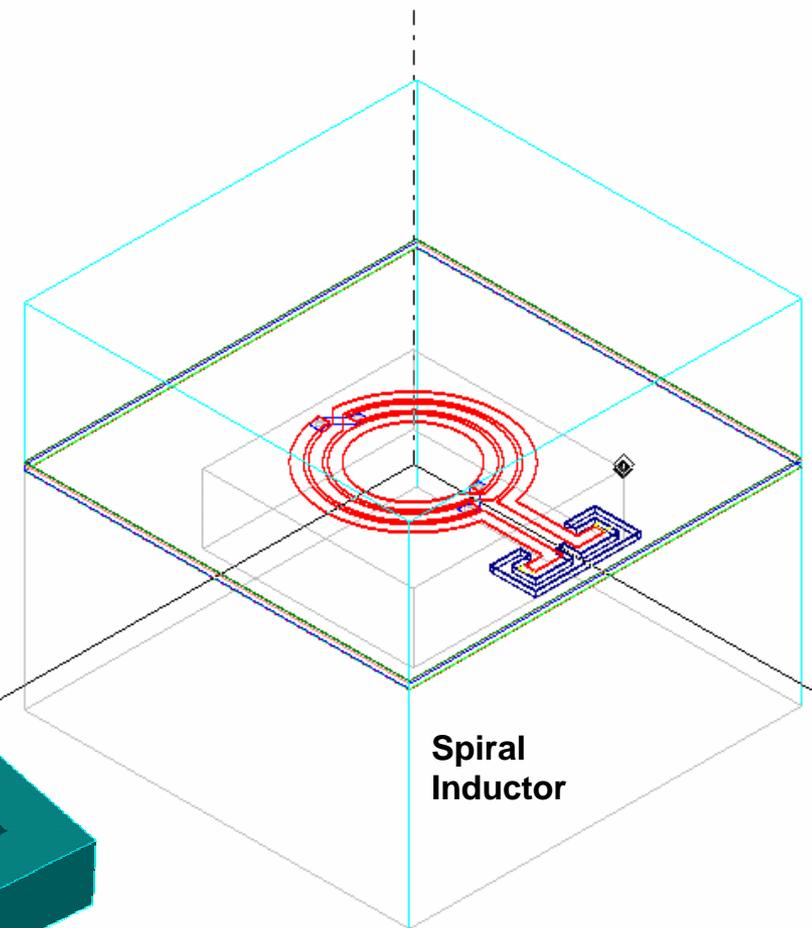
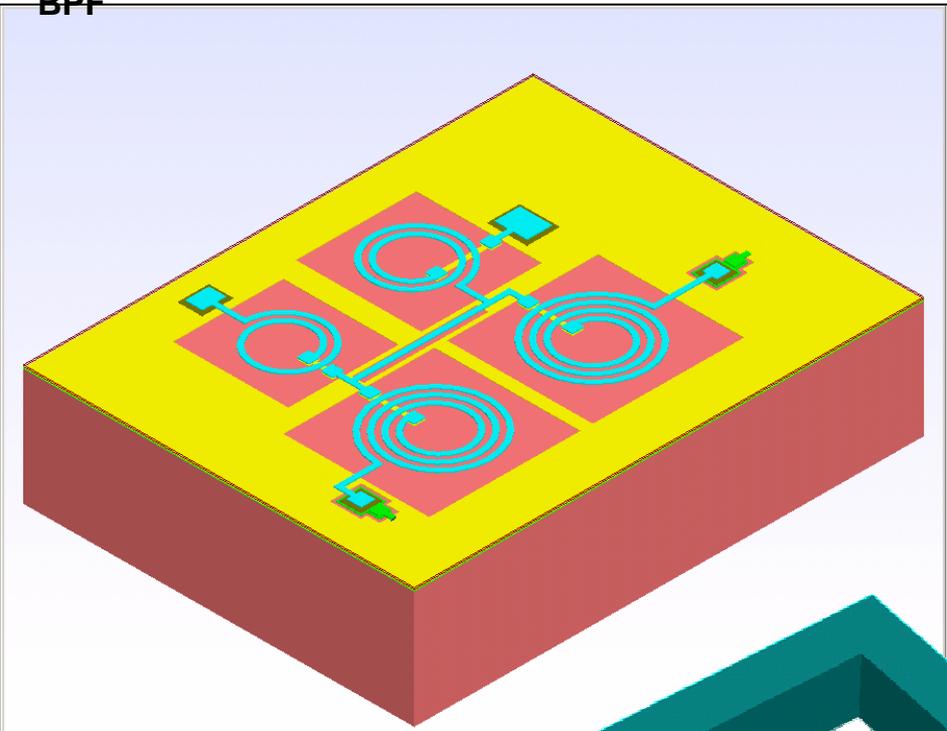
UMC

Outline

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

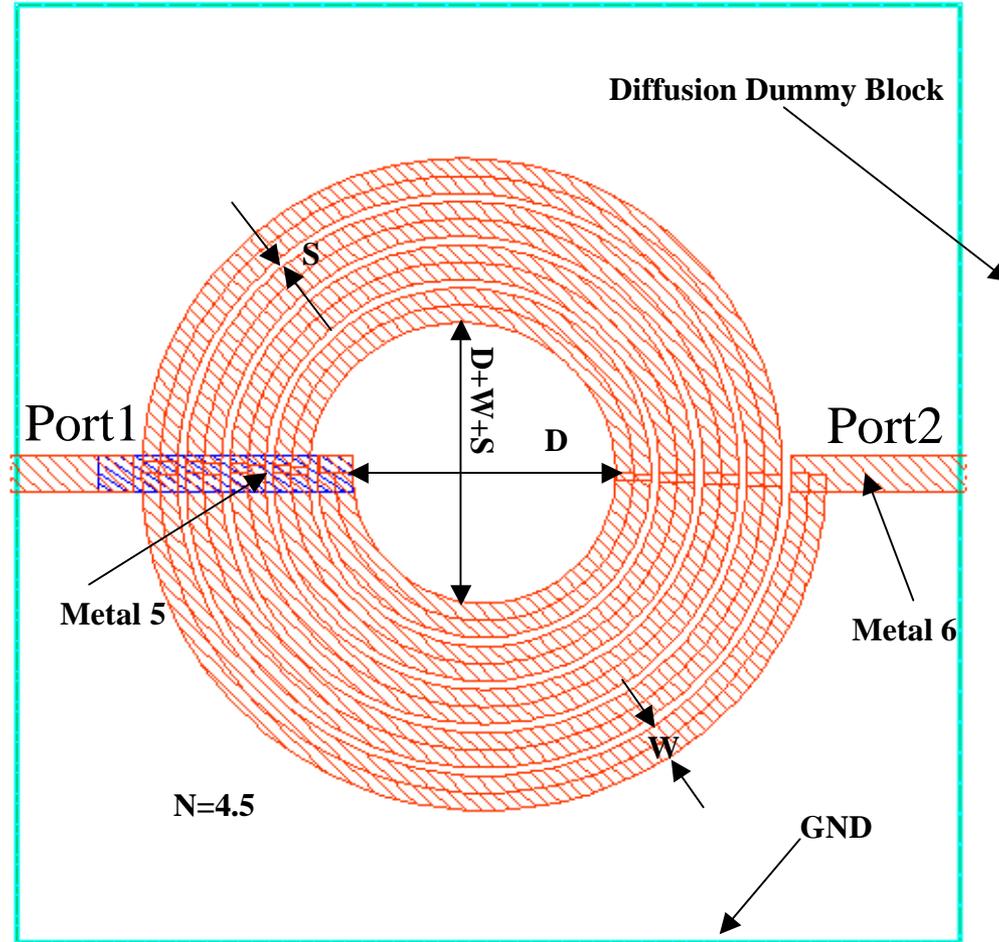
On-Chip Spirals

BPF



RF Balun

Ideal Circular Inductor



Geometrical Parameters

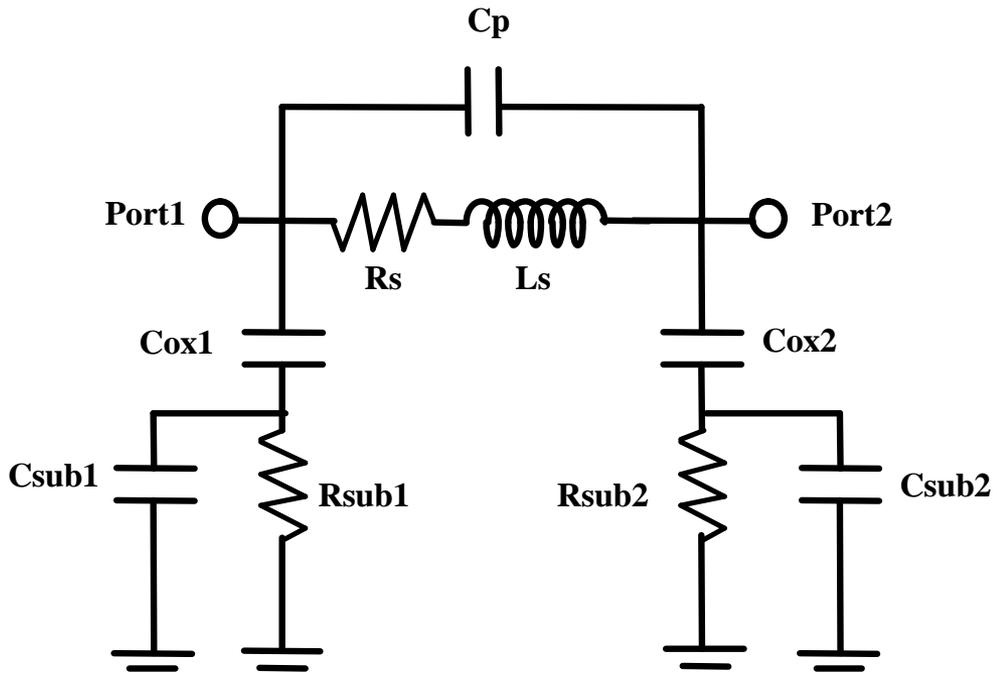
Diameter

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**

Outline

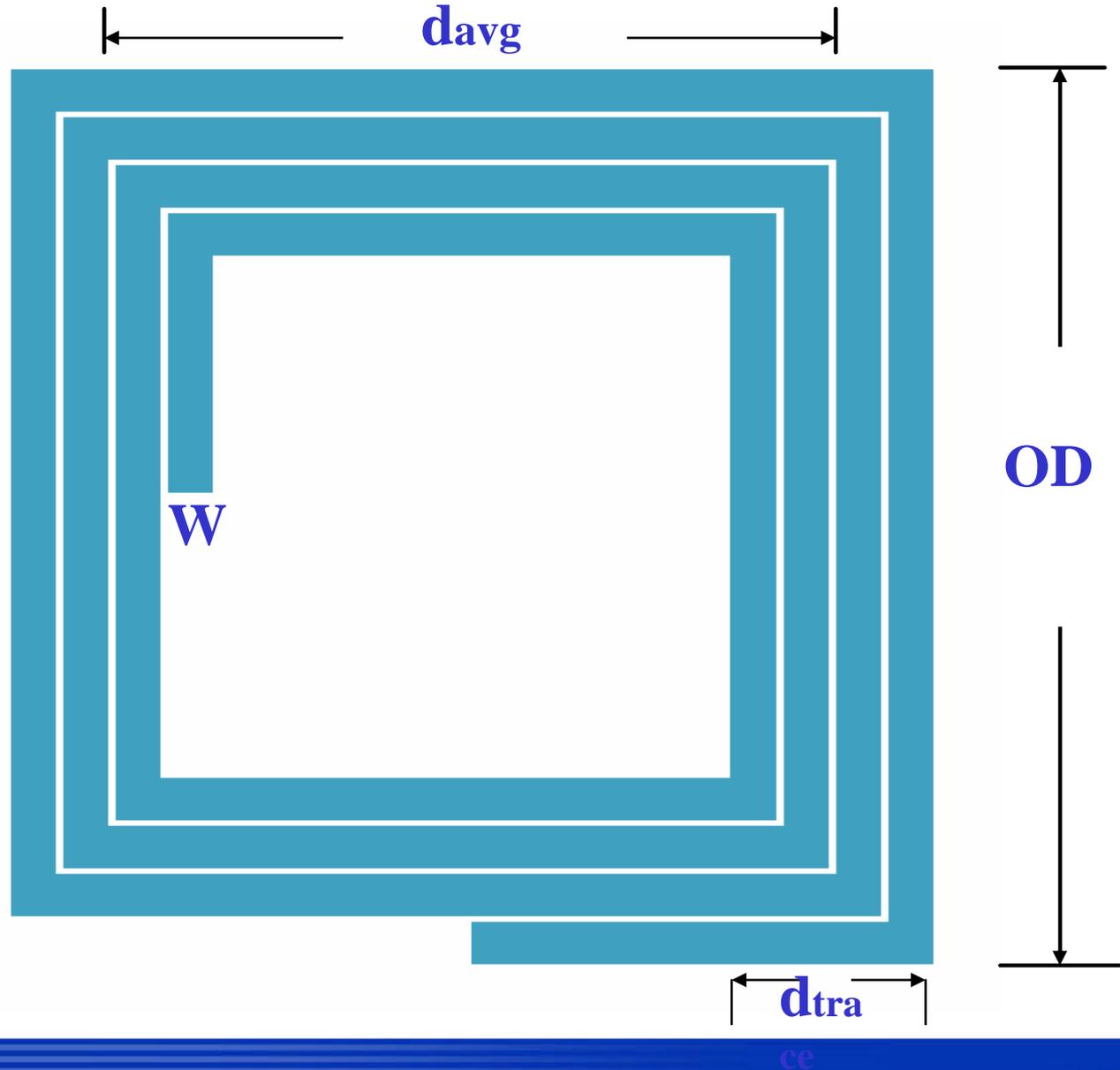
- Introduction
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Foundry's Inductor Model and Library

- 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

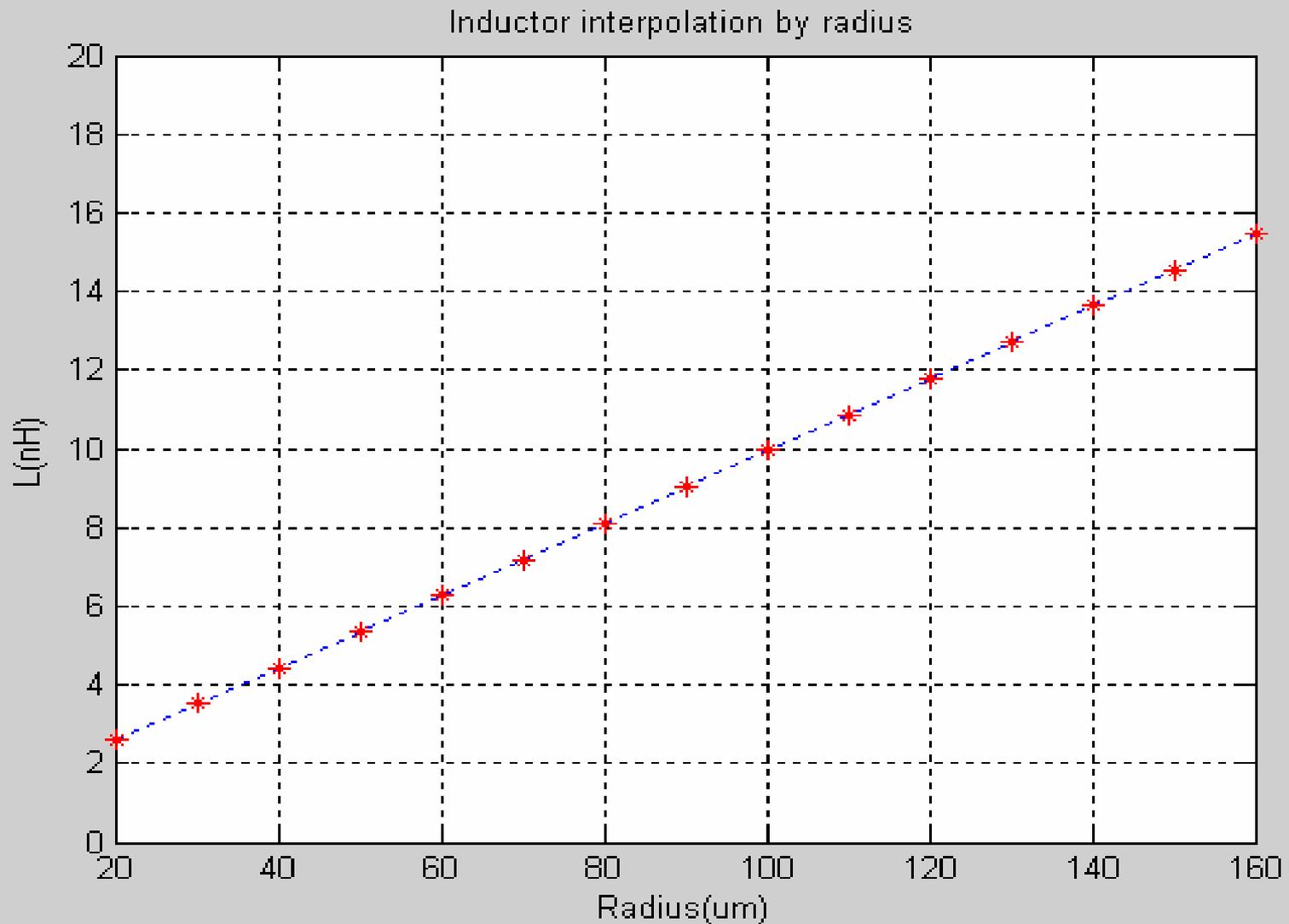
r : percentage of the inductor area that is filled by metal traces.

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

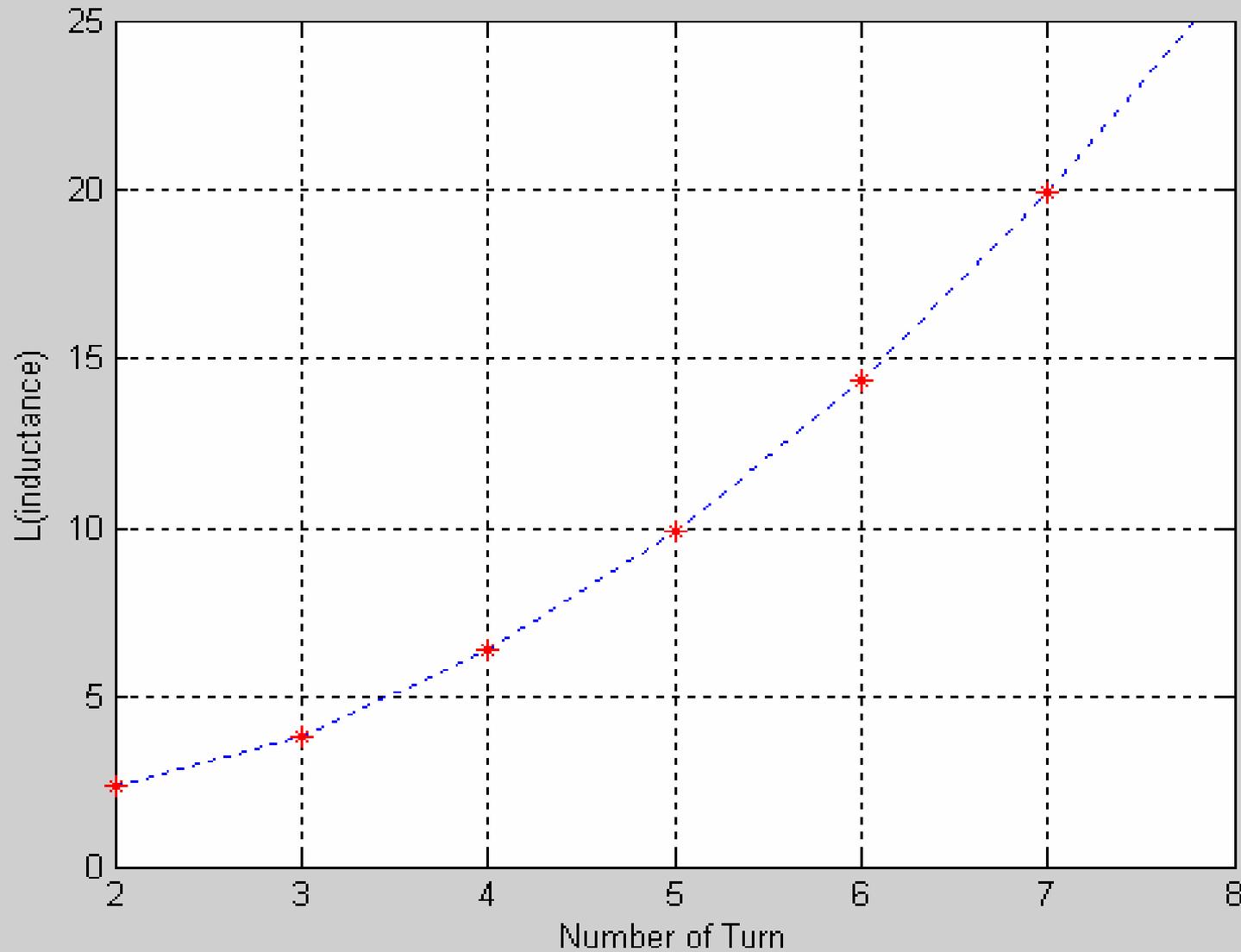
Measured Inductor Library

- 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



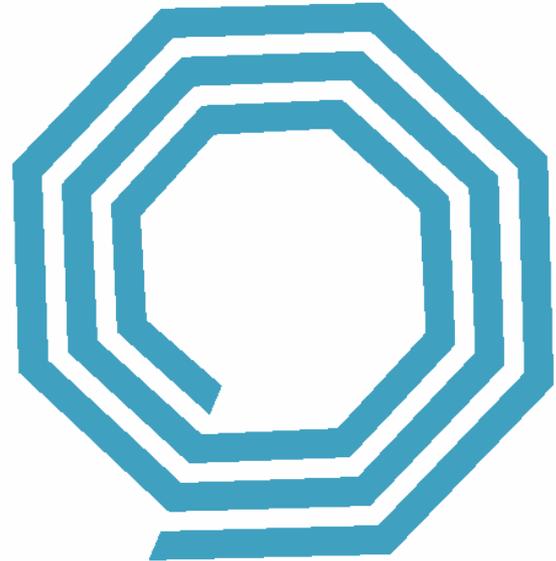
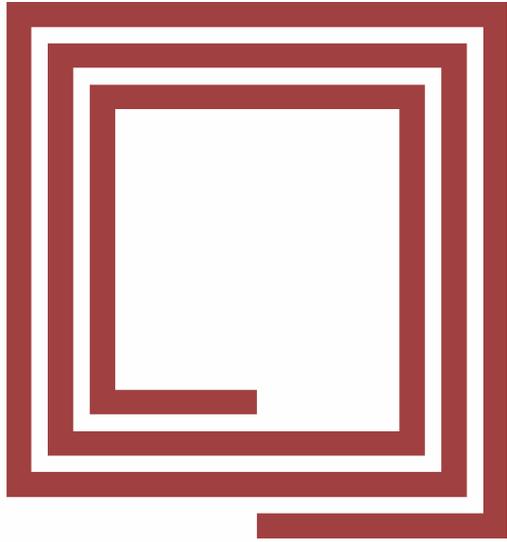
Scalable Inductance v.s. turns



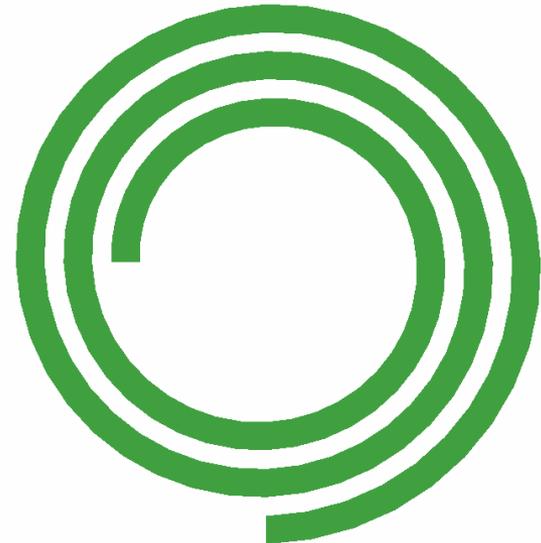
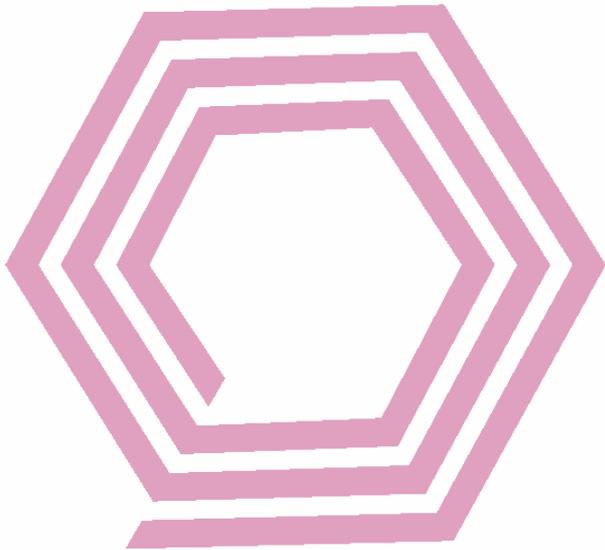
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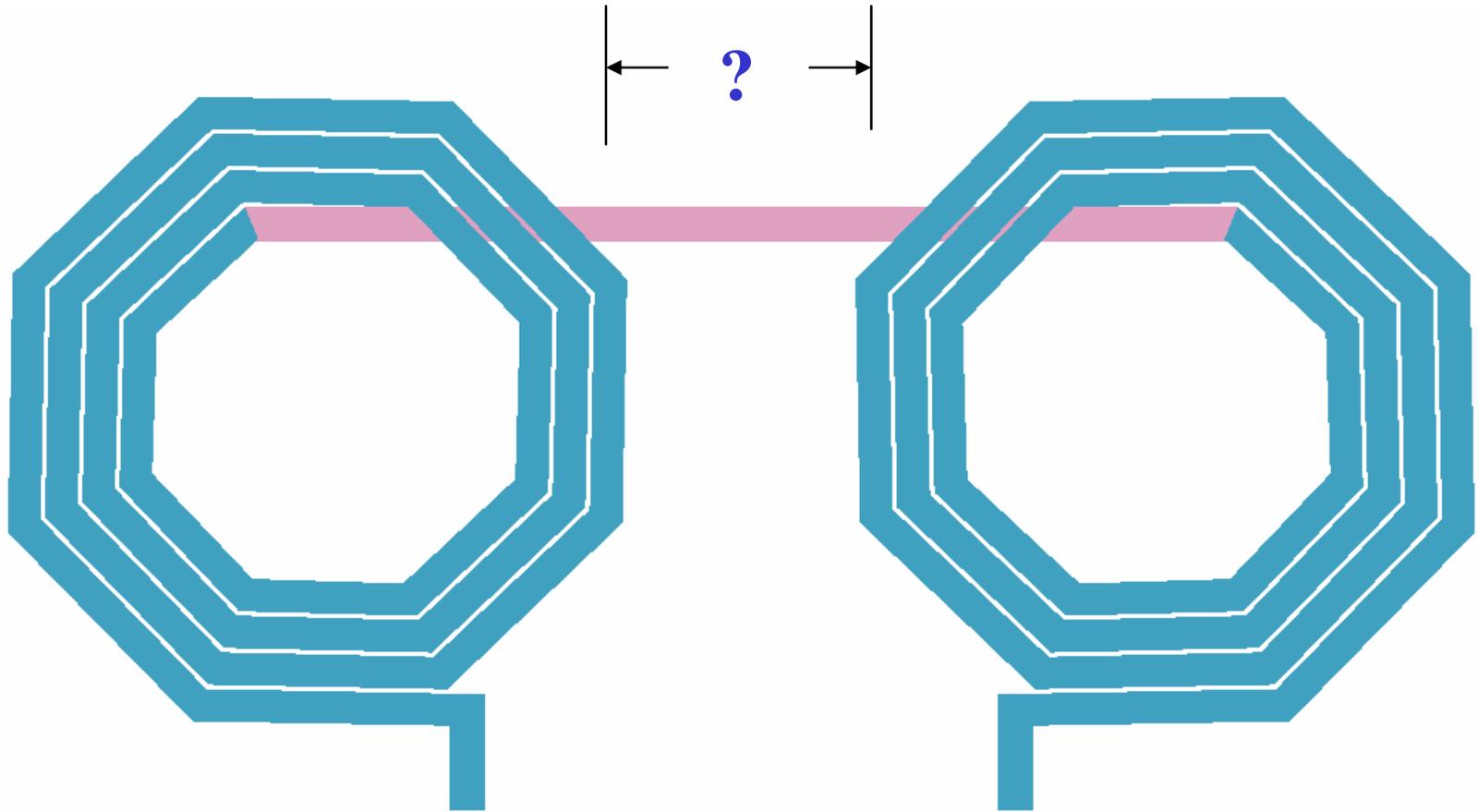
Various Spiral



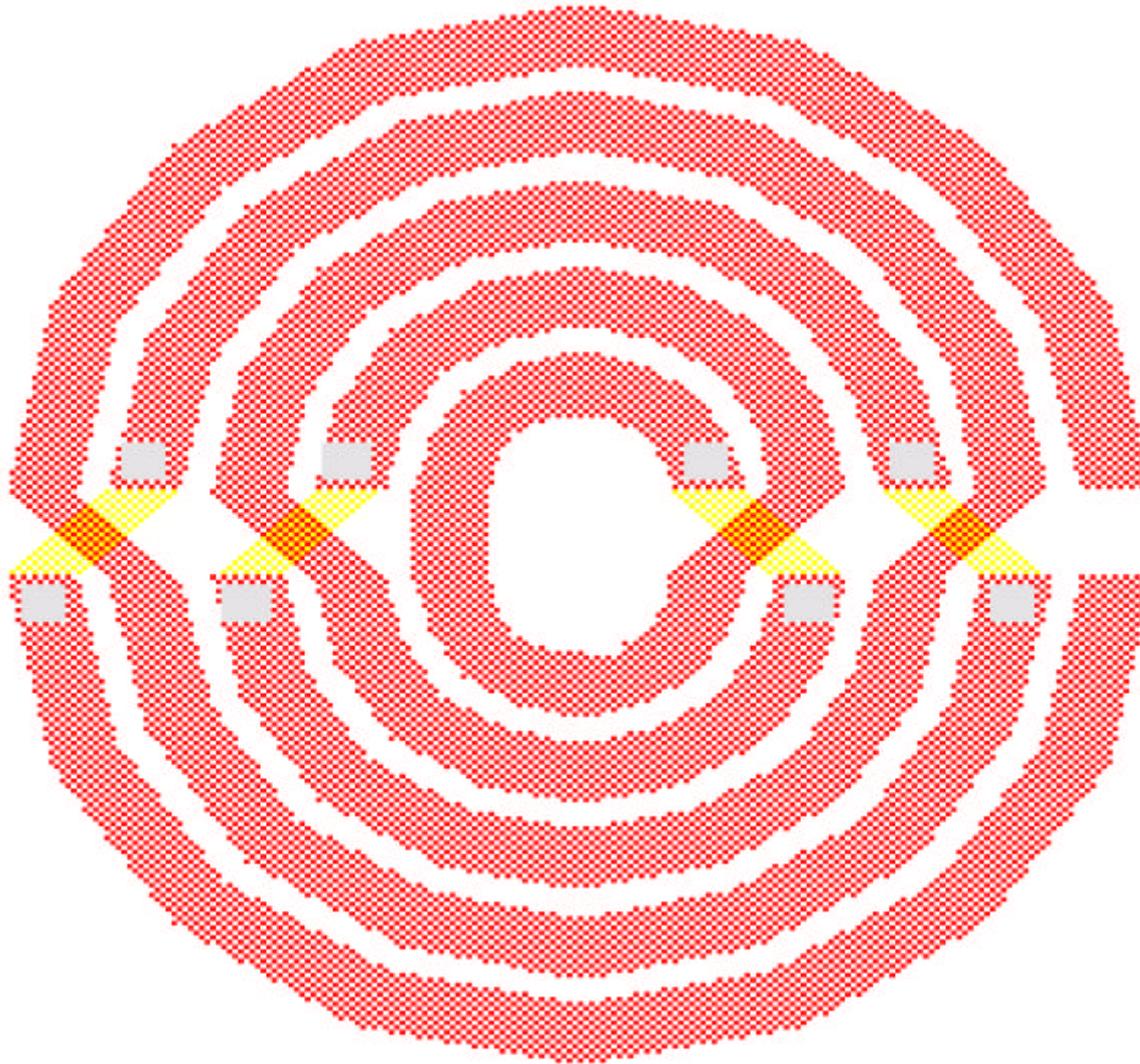
?



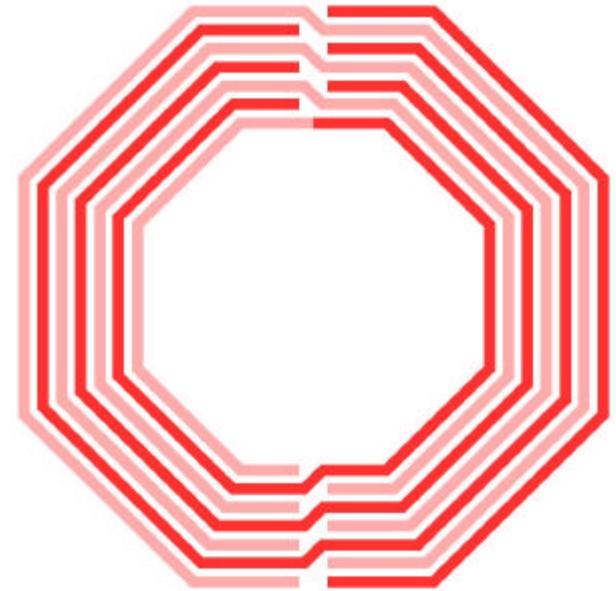
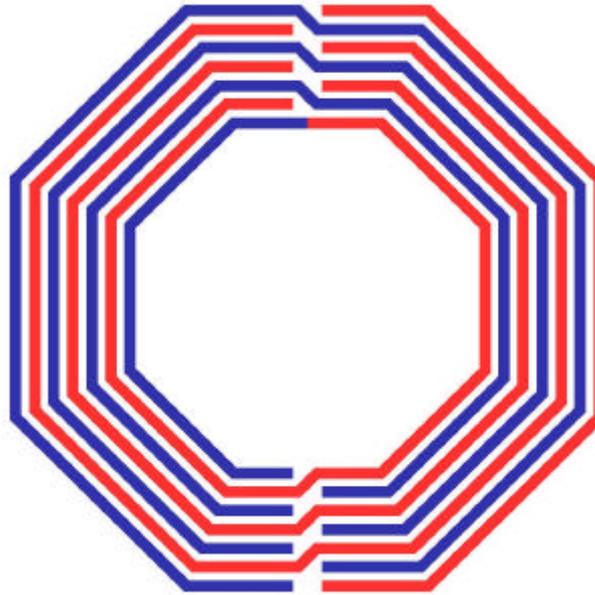
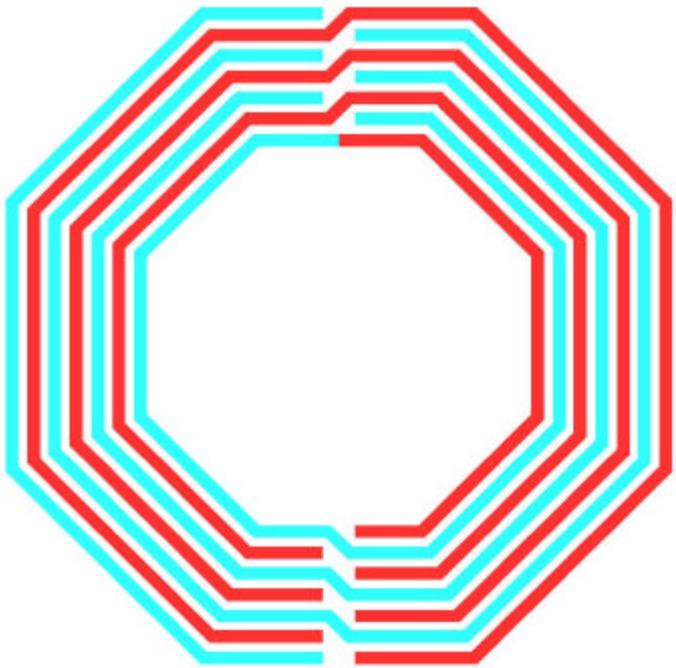
Differential Spiral



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

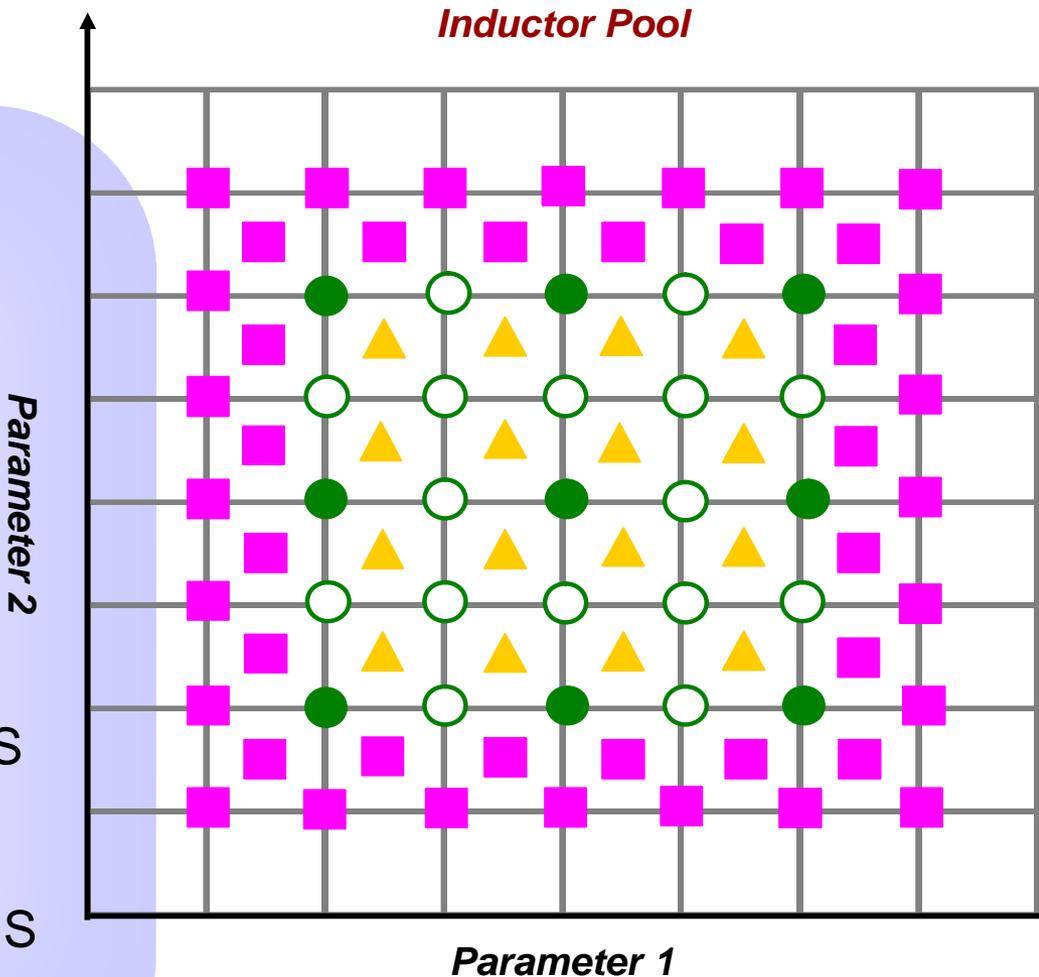
- Current Version 9.0
- A true **3D** Electromagnetic-Based Design Tool
- Widely used in Package, Wave guide and Antenna
- **UMC** is the first Foundry that provide the methodology for using 3D EM design tool to support RFIC design

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?

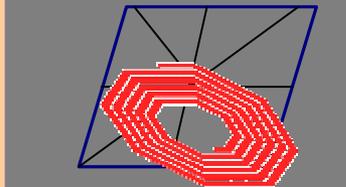
➤ *Special Inductor Design*

Novel Inductor Design

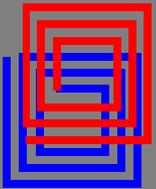
3-D EM simulation

S-Parameter

Designer



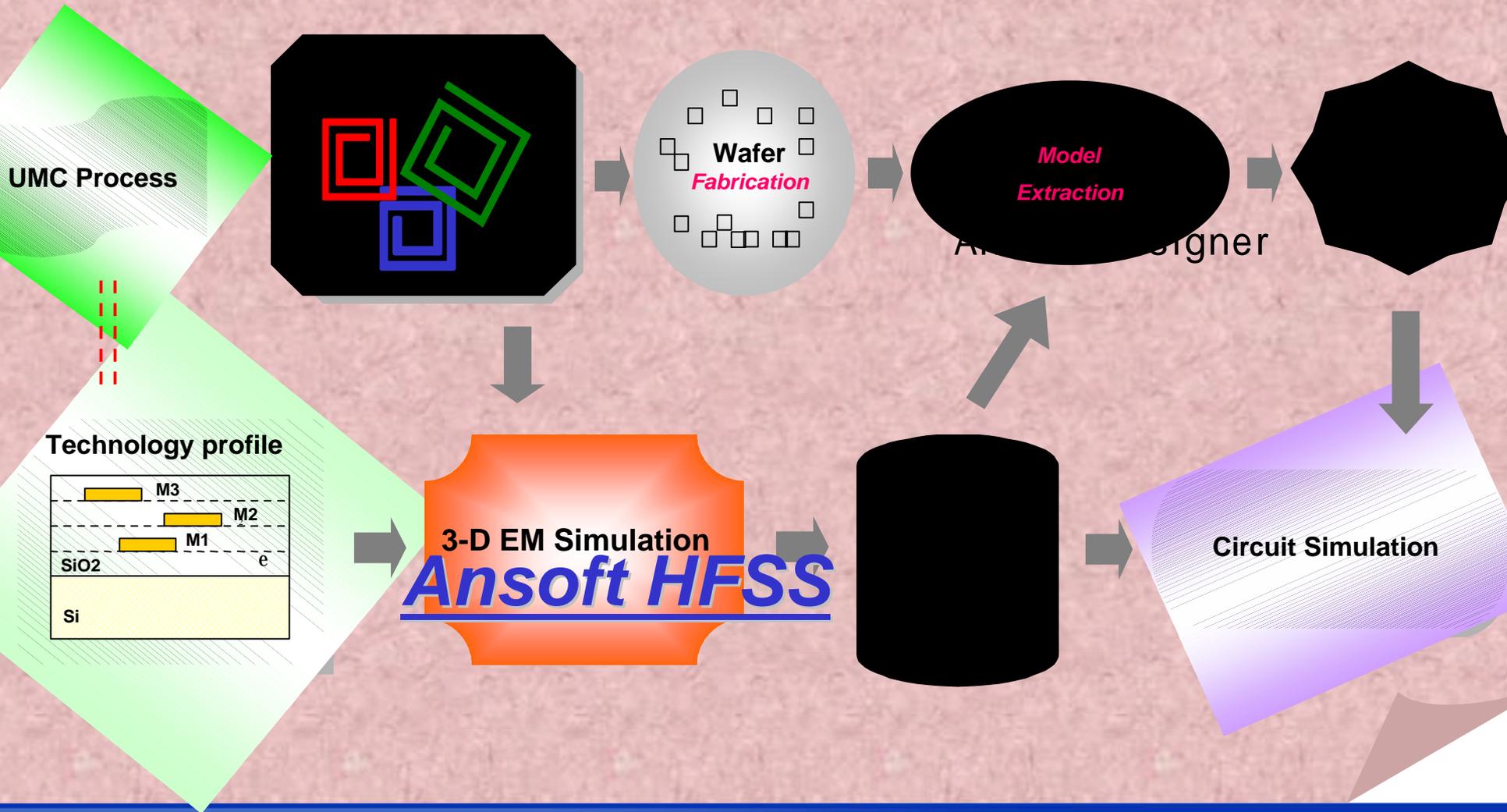
Pattern shielding ground



Transformer or stacked or others

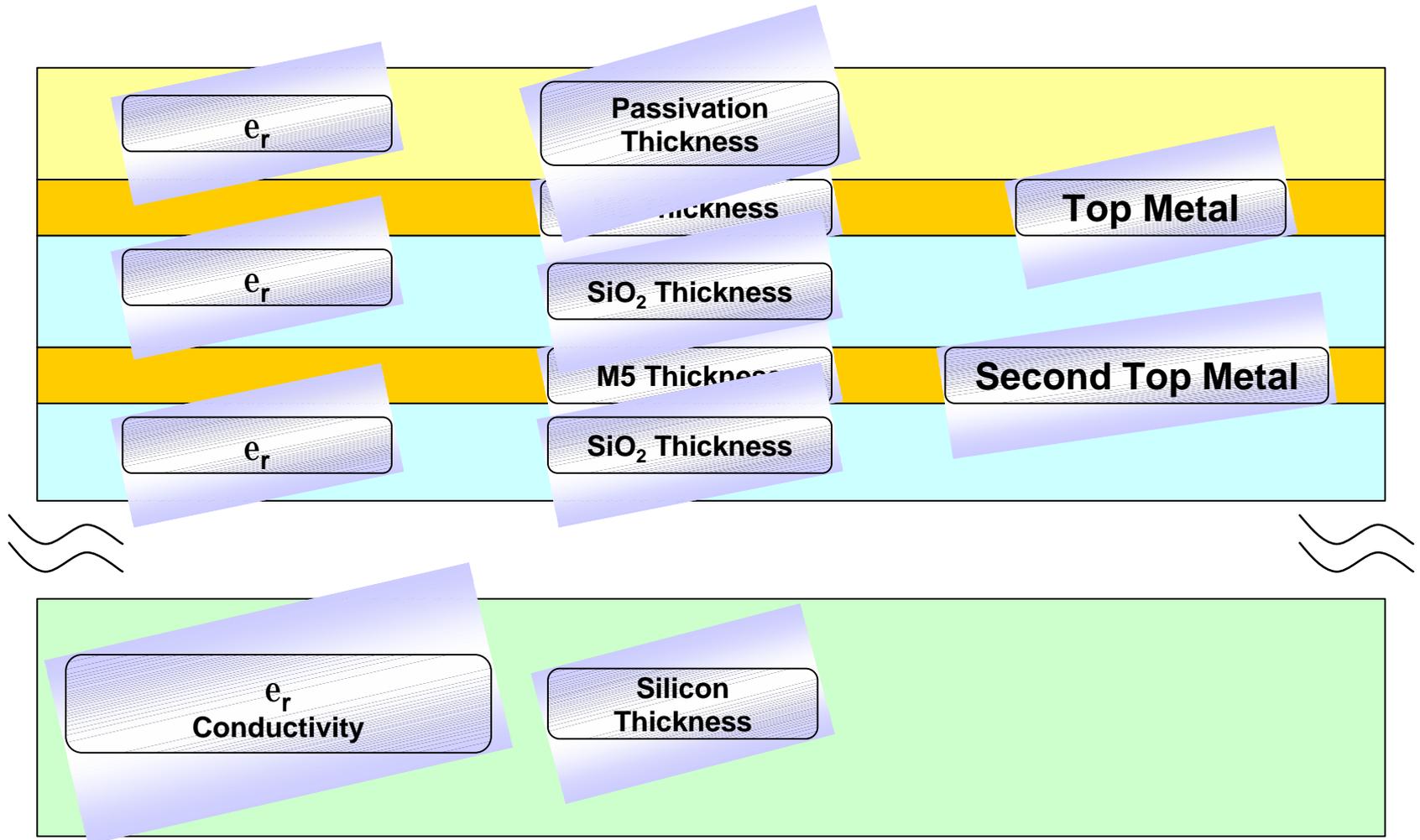
UMC's New Approach (3)

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

Setup...

Spiral Name:

Round Spiral Square Spiral

Overall Dimension:

Material Width:

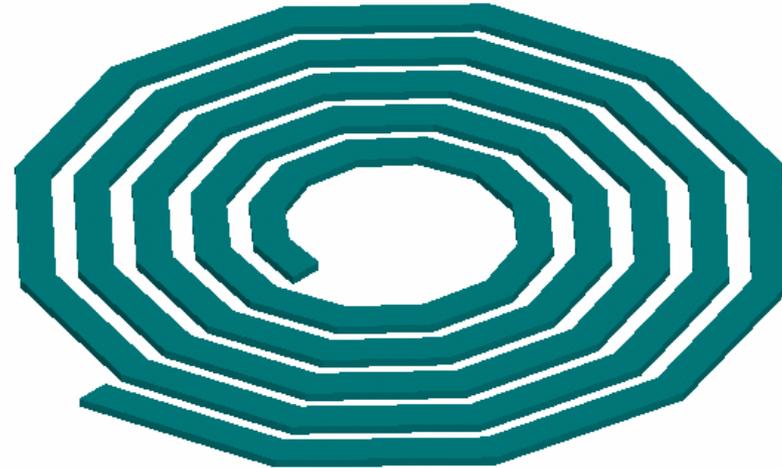
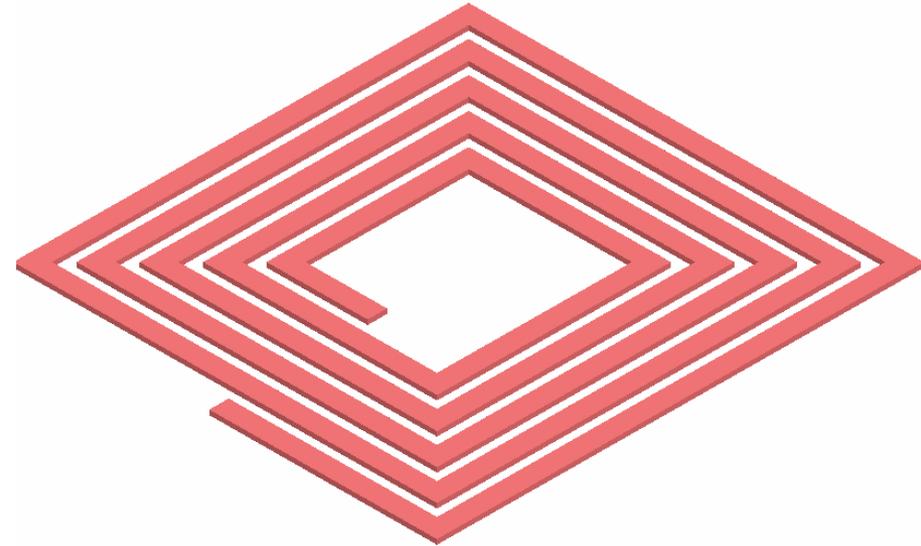
Material Thickness:

Turn Spacing:

The spiral can be created in increments of 1/4 turns.

Number of Turns:

Clockwise Counter-Clock



EMDM Inductor Design Flow

ANSOFT OPTIMETRICS "par_rd_ind_roadshow"

Setup	GetTurns	OverallDia	SpiralS	SpiralW	GetSegments	TotalThick	L_nH_2p4g	L_nH_5p8g	Q_Value_2p4g	Q_Value_5p8g	Sensitivity Done
setup1	1.5	129	2	10	8	2	0.667043	0.658309	8.0866	10.3416	N
setup2	2.5	153	2	10	8	2	1.30226	1.2889	7.52438	9.91424	N
setup3	3.5	177	2	10	8	2	2.15776	2.23567	8.67718	9.45335	N
setup4	4.5	201	2	10	8	2	3.61447	3.94912	8.08764	7.28297	N
setup5	5.5	225	2	10	8	2	5.3237	6.56917	8.66663	5.17649	N

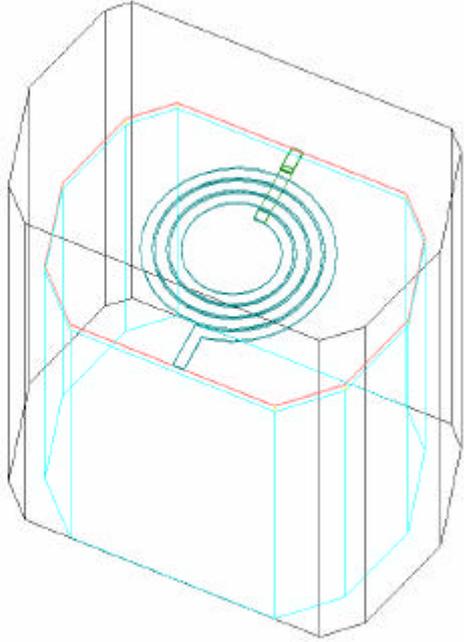
Variable Value

GetTurns	3.5
OverallDia	177
SpiralS	2
SpiralW	10
GetSegments	8
TotalThick	2

ANSOFT OPTIMETRICS "par_rd_ind_roadshow"

SETUP: setup3

Variable	Value
GetTurns	3.5
OverallDia	177
SpiralS	2
SpiralW	10
GetSegments	8
TotalThick	2



Help

Exit

Help

Exit

Optimetrics Version 2.5.04 Copyright 1984-2002 Ansoft Corporation

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

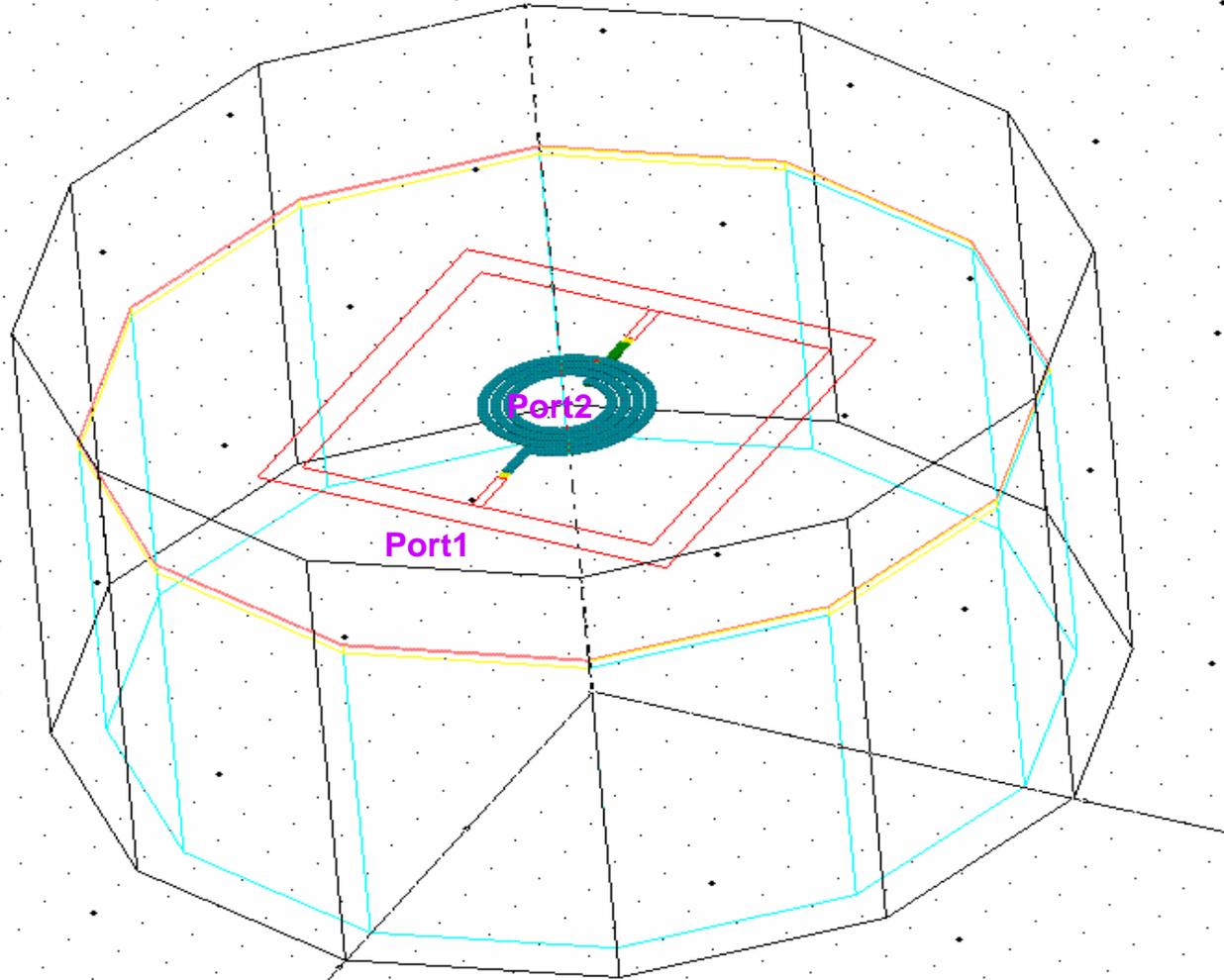
Group2=>

- 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)

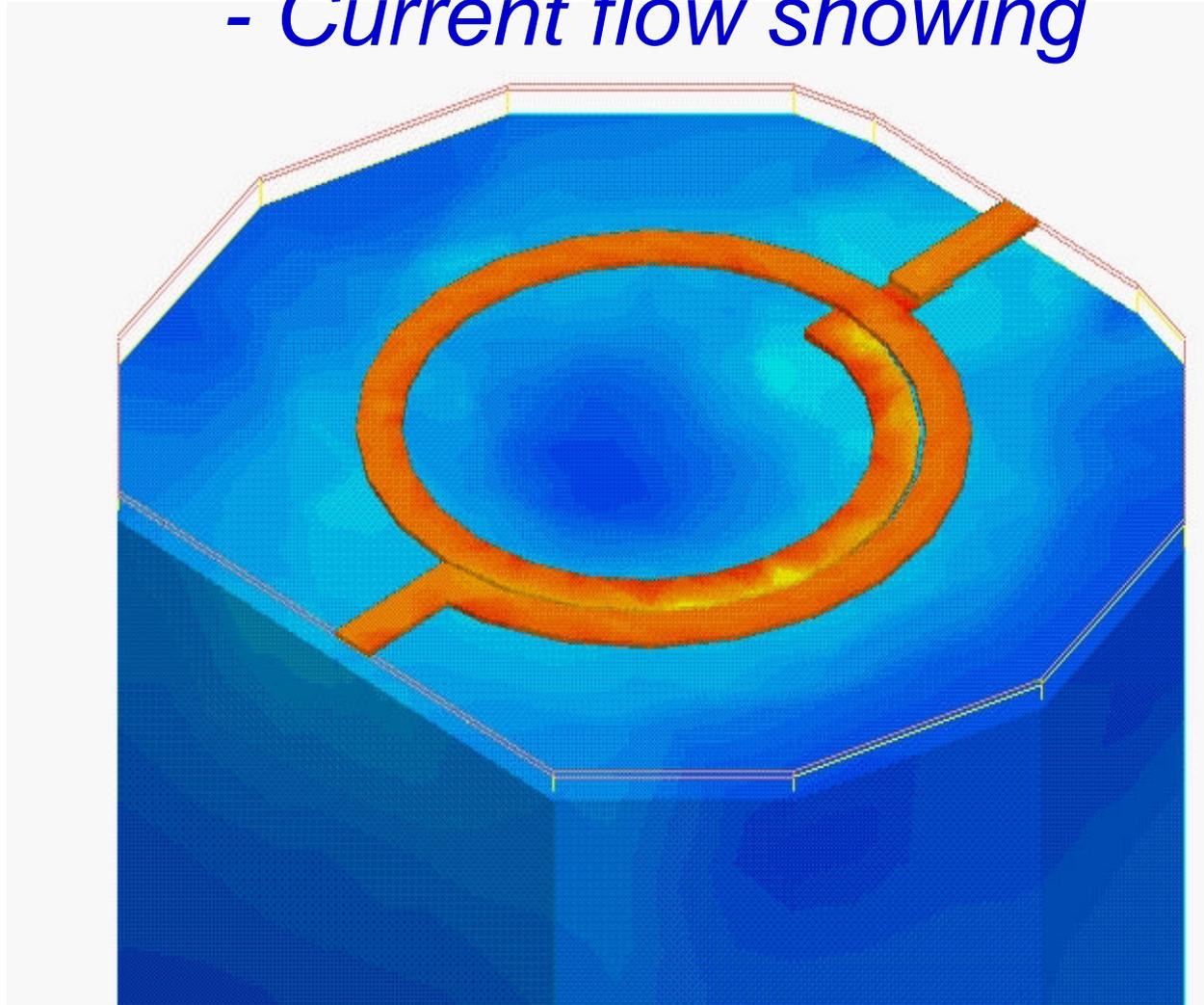
- Inductor Simulation Profile



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

Results and Discussion (3)

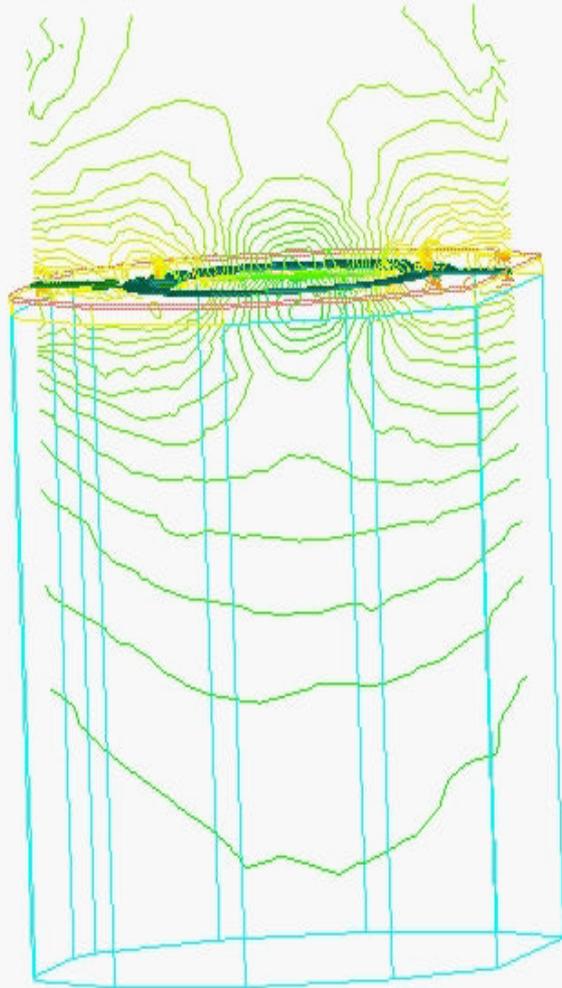
- Current flow showing



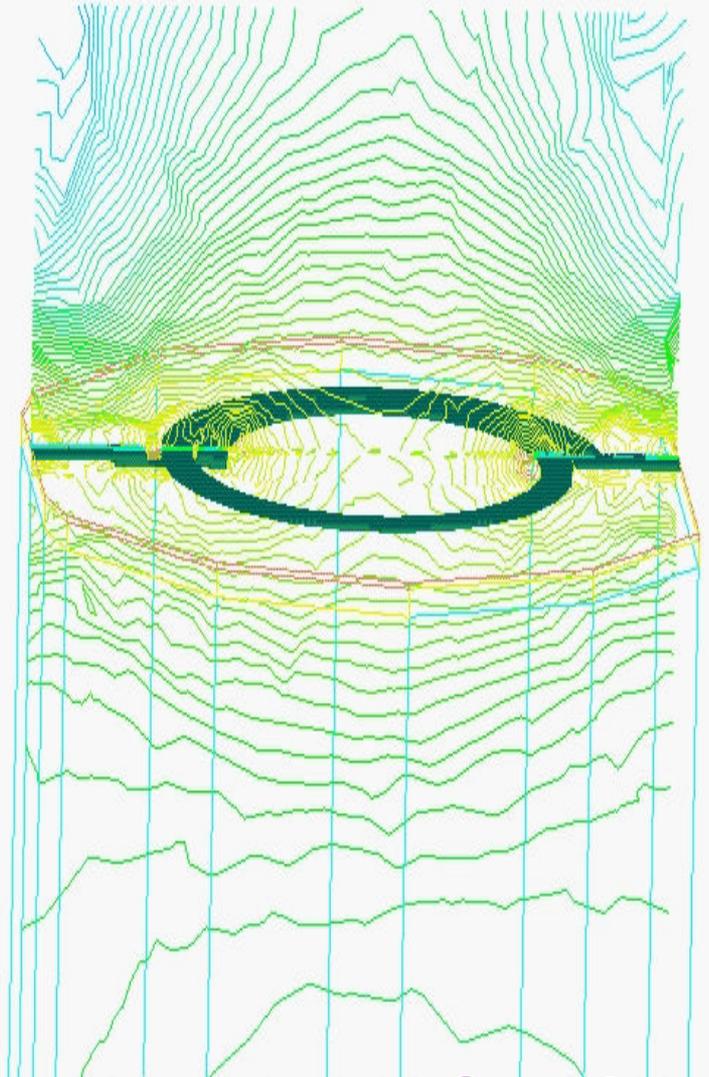
➤ Current flow @ 5.8GHz

Results and Discussion (4)

- E&M field showing



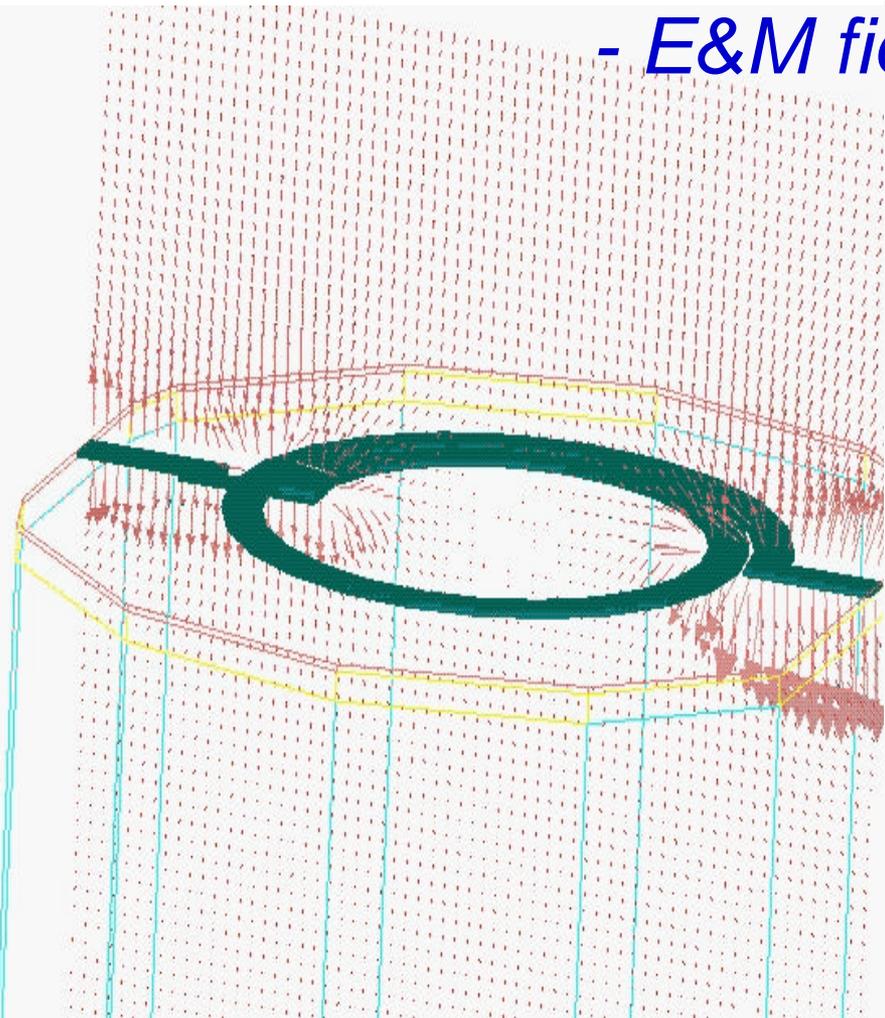
Mag of Electric field @ 5.8GHz



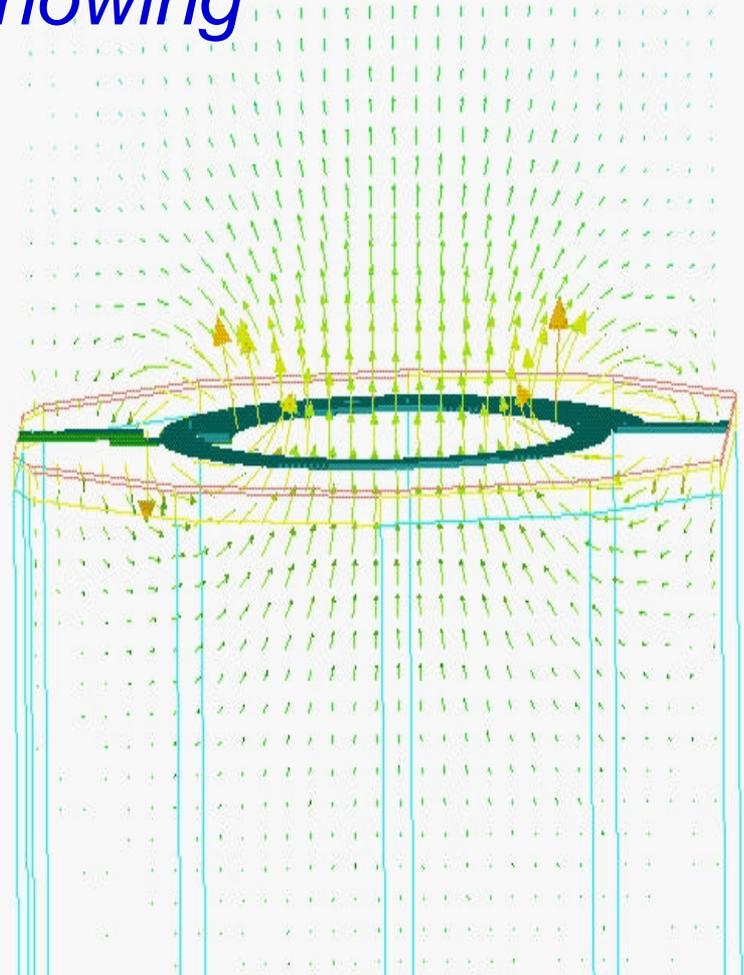
Mag of Magnetic field @ 5.8GHz

Results and Discussion (5)

- E&M field showing



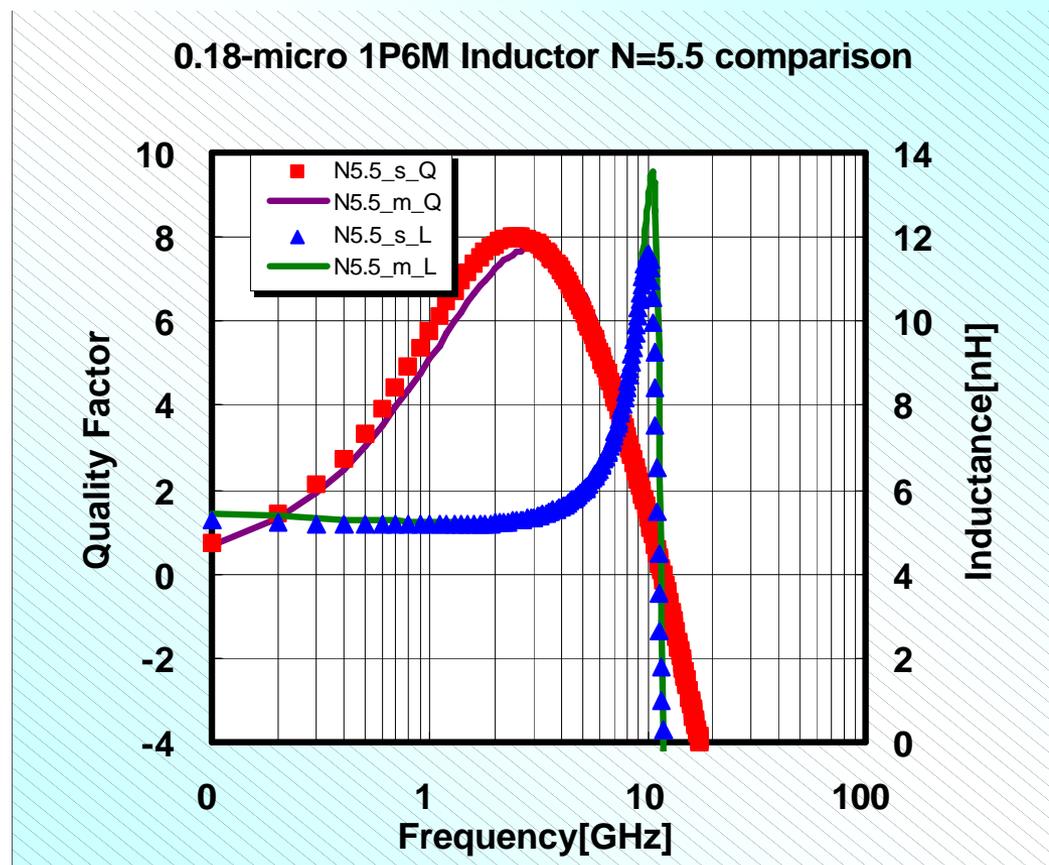
Vector of Electric field @
5.8GHz



Vector of Magnetic field
@ 5.8GHz

Results and Discussion (6)

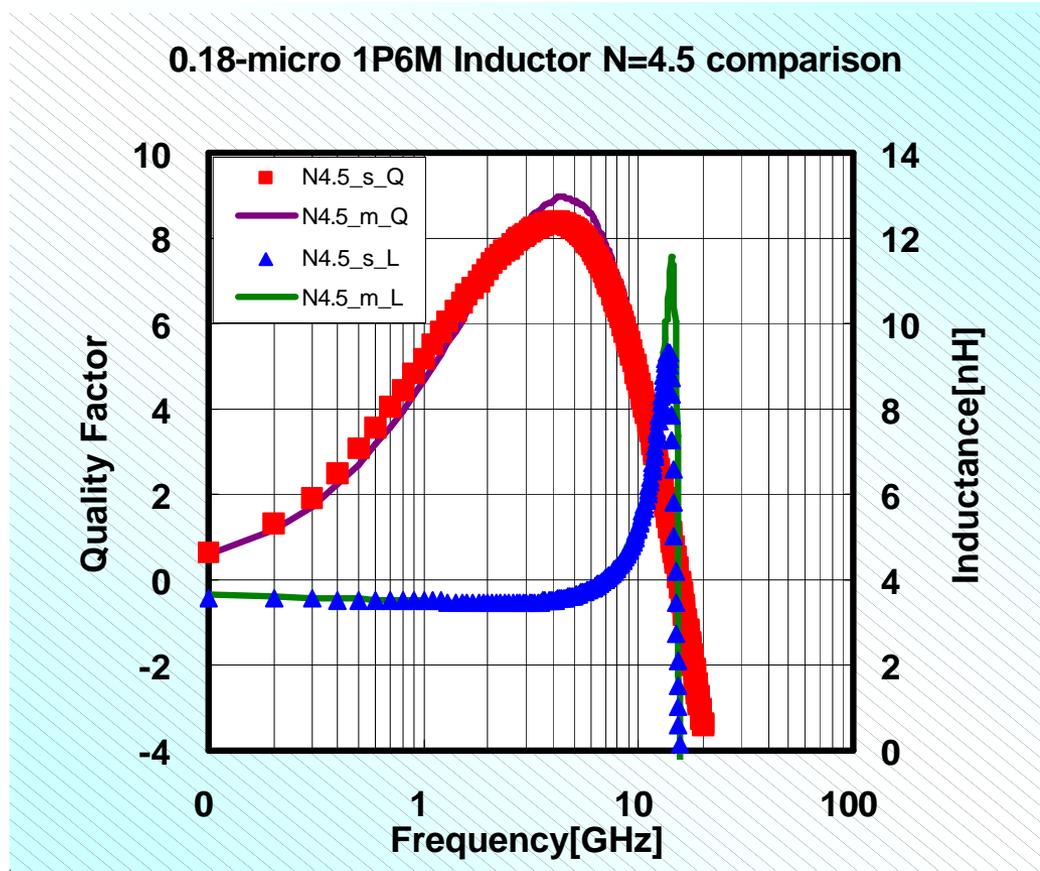
- L/Q simulation & measurement comparison



- Width=10 μ m, Spacing=2 μ m, Di= 85 μ m, Turns=5.5, Al=20KA

Results and Discussion (7)

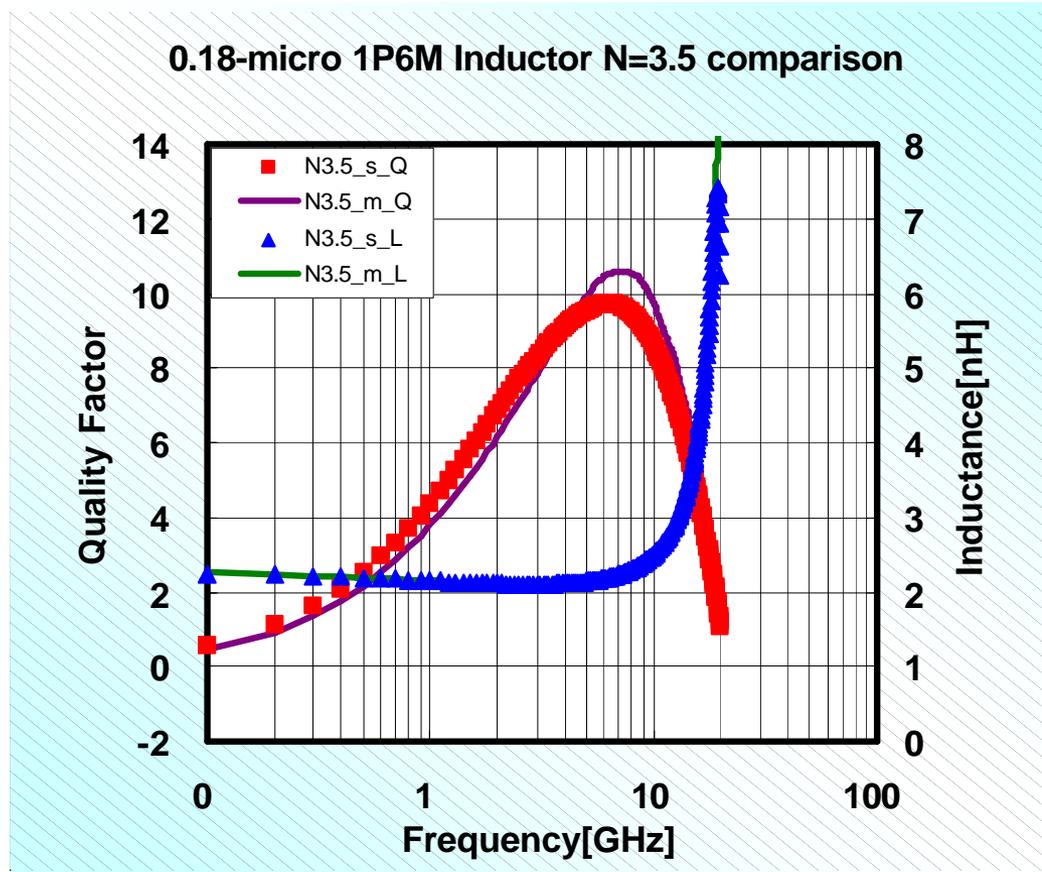
- L/Q comparison



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

Results and Discussion (8)

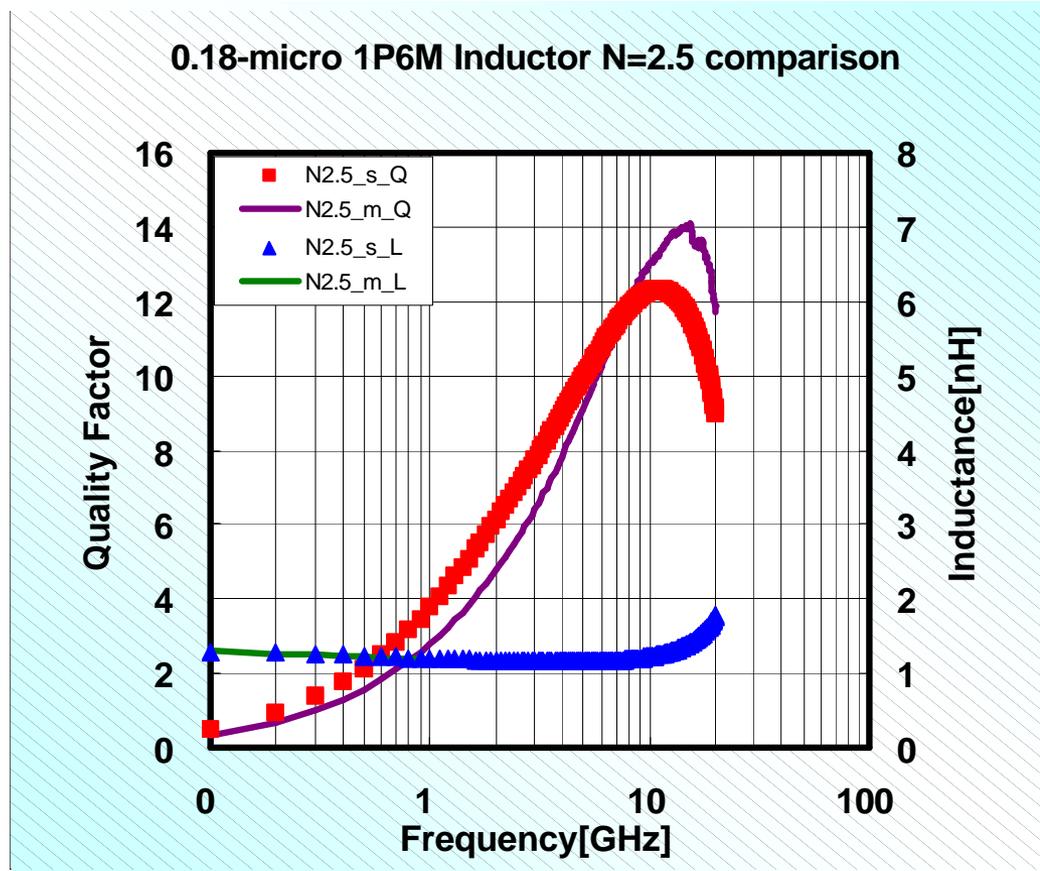
- L/Q comparison



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

Results and Discussion (9)

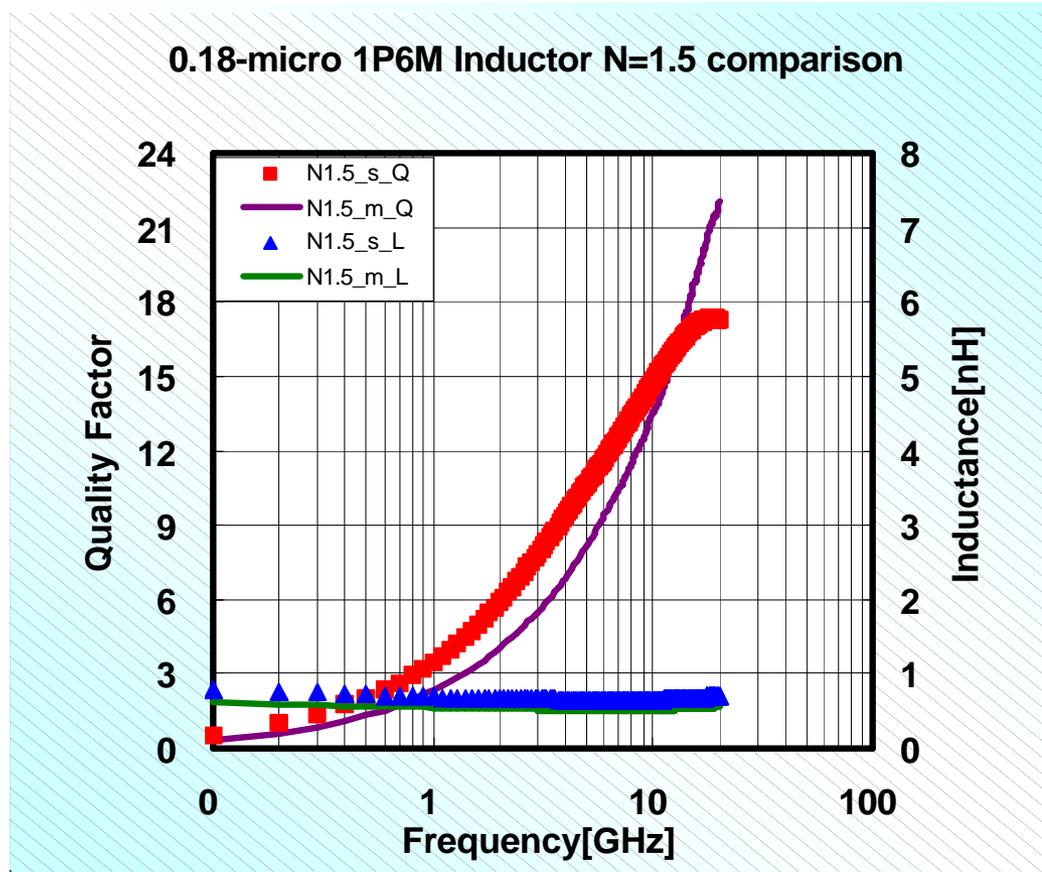
- L/Q comparison



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

Results and Discussion (10)

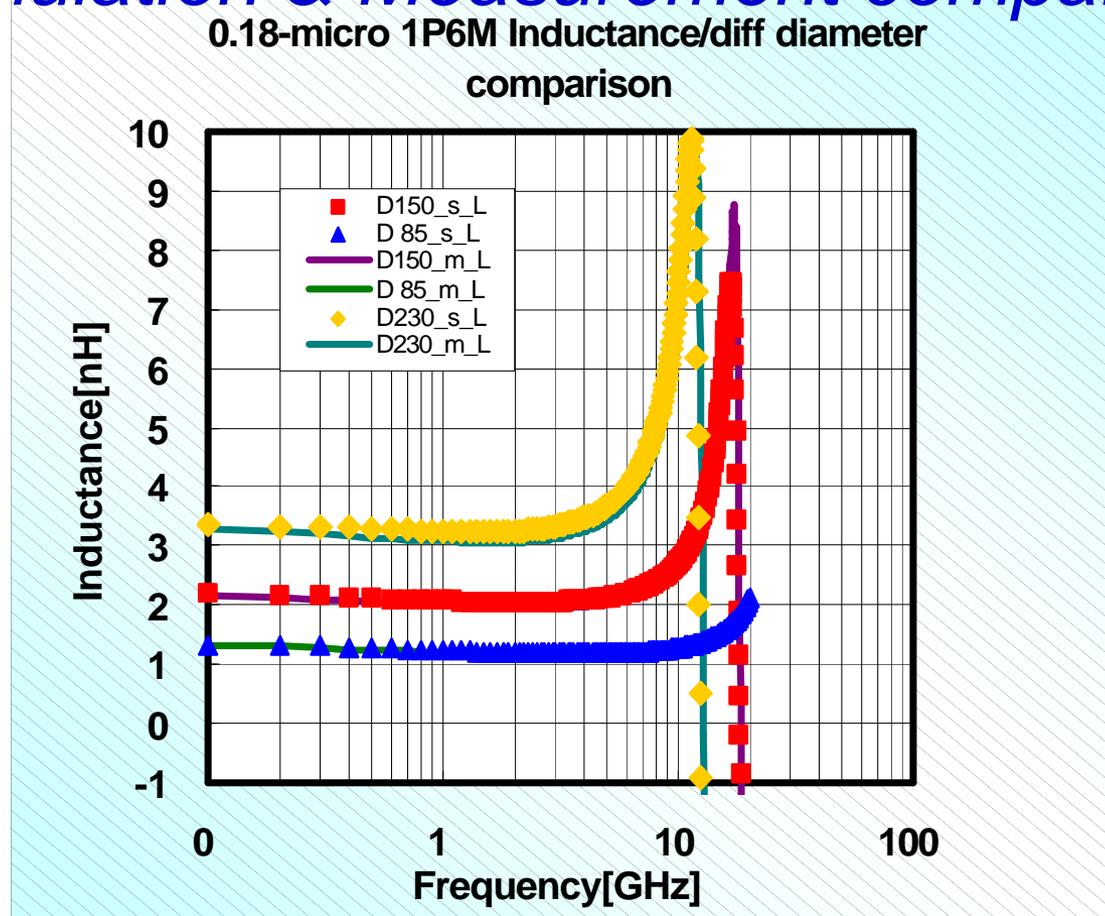
- L/Q comparison



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

Results and Discussion (11)

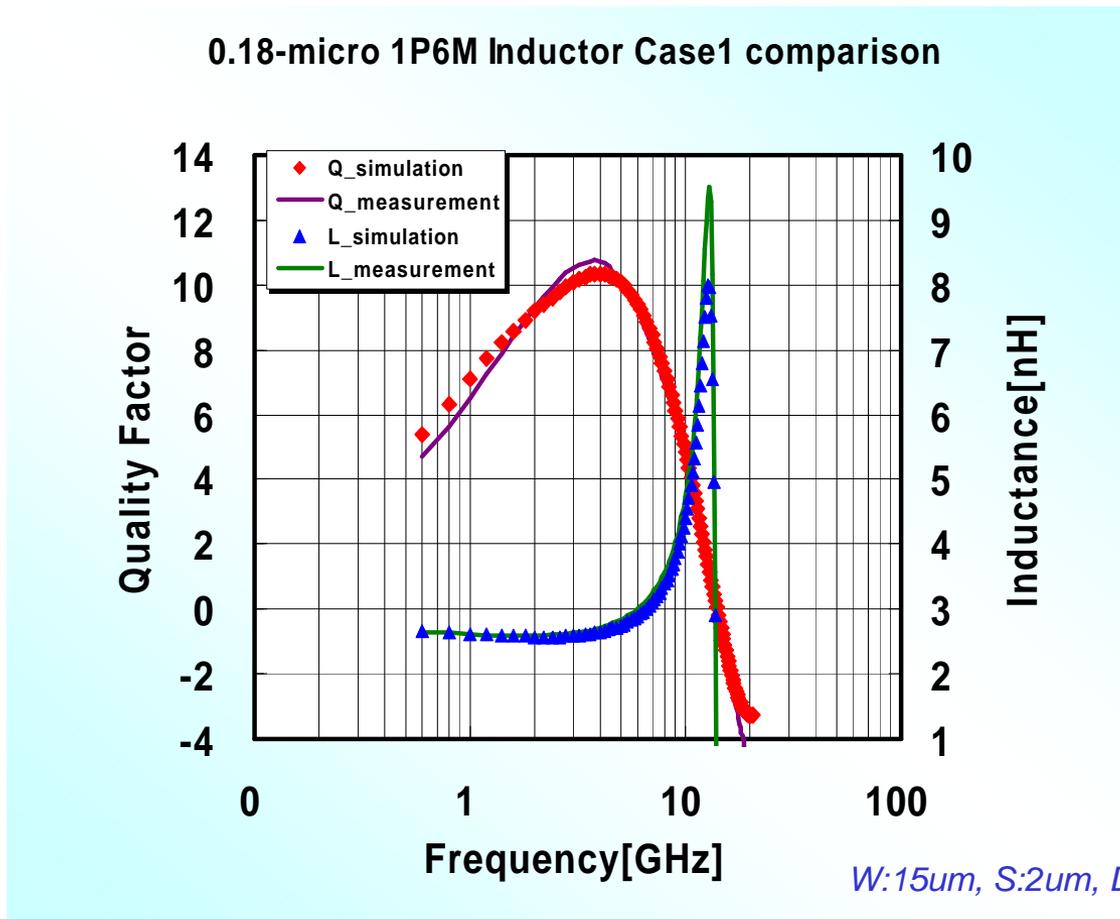
- Simulation & Measurement comparison



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

Results and Discussion (12)

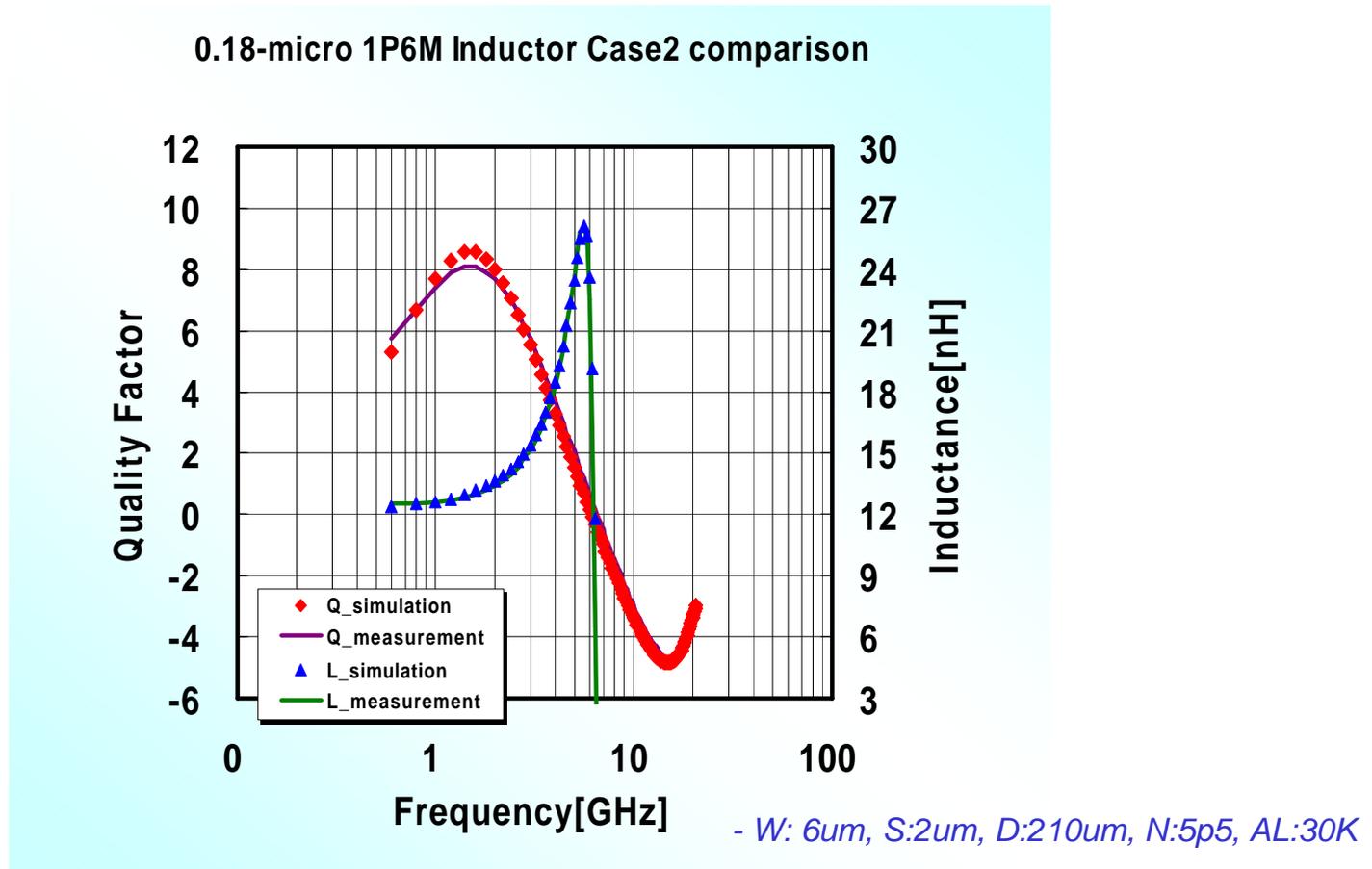
- Inductance & Q-value Comparison - (Case1)



- **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)



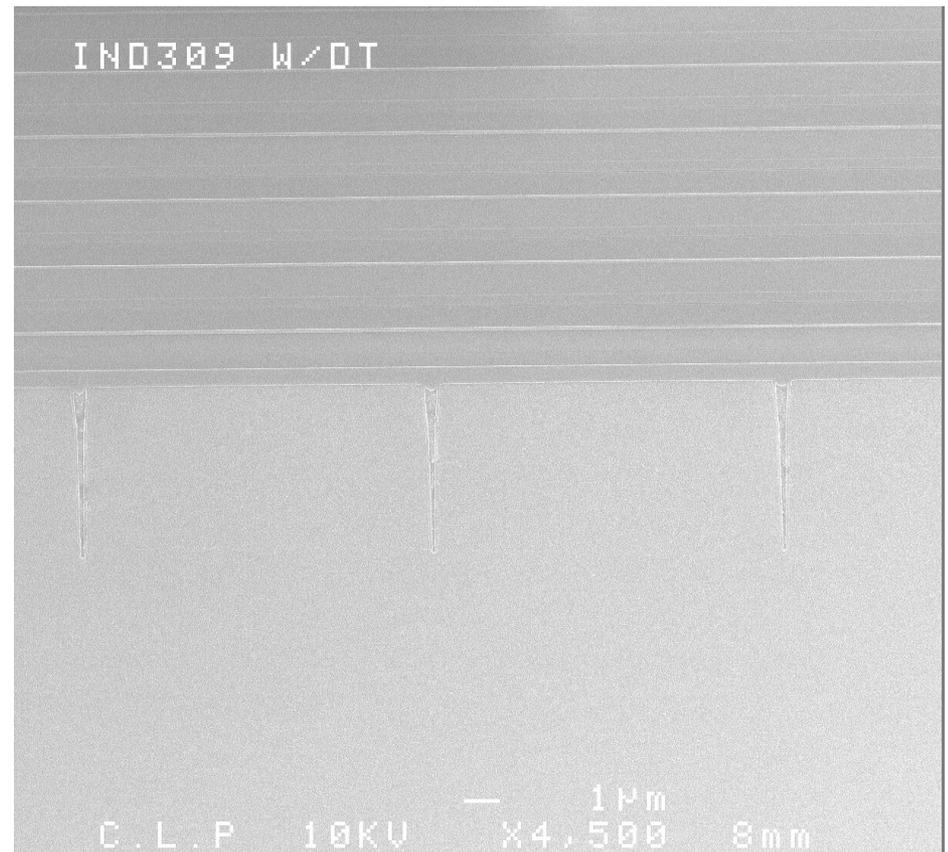
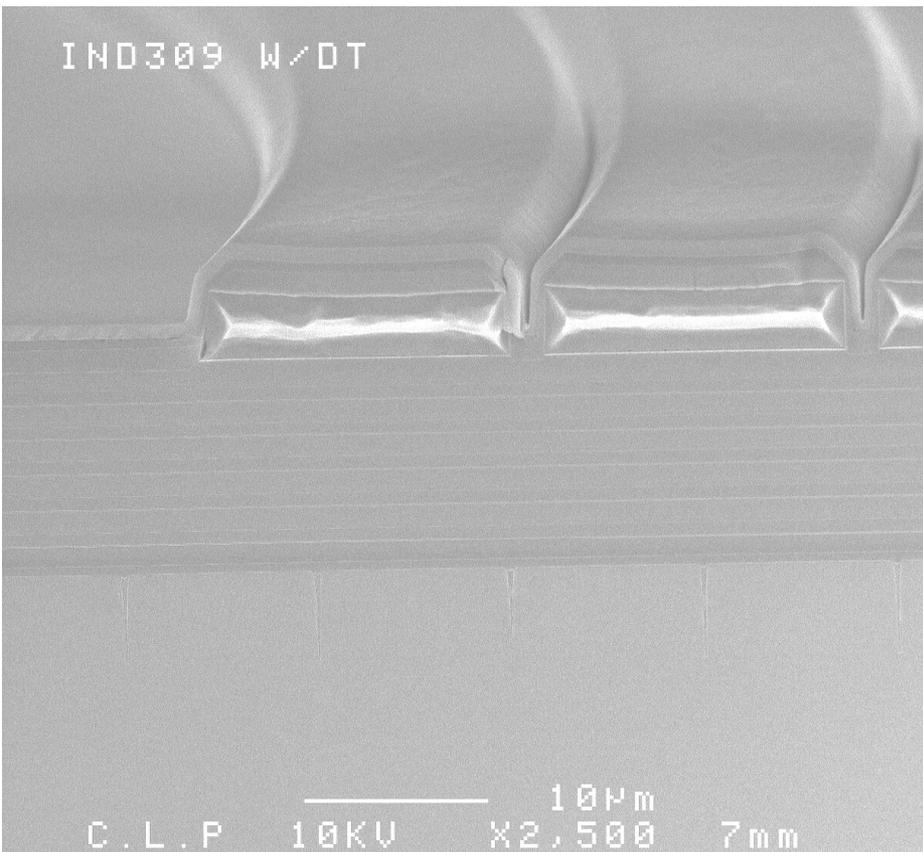
➤ **Simulation: $Q_{max} = 8.57$ @ 1.4GHz, $F_{sr} = 6.2$ GHz.**

➤ **Measurement: $Q_{max} = 8.1$ @ 1.4GHz, $F_{sr} = 6.4$ GHz.**

Results and Discussion (14)

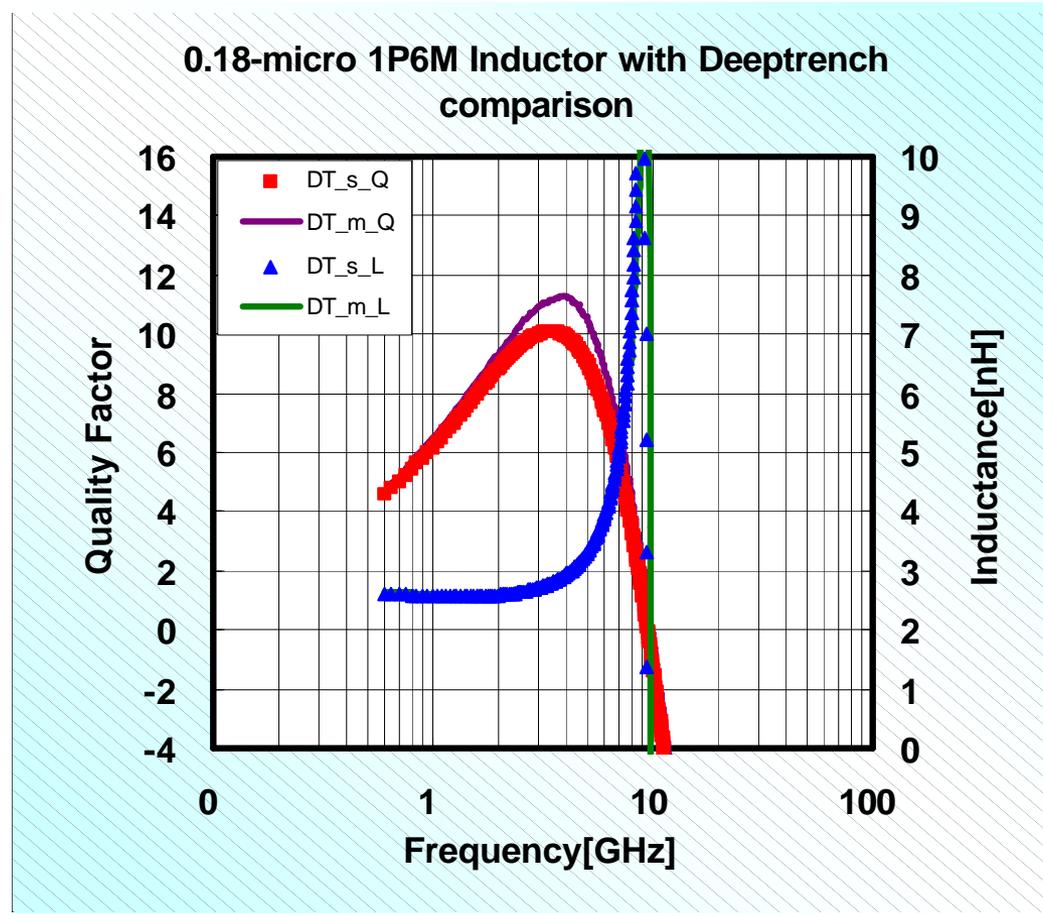
- Deep-trench pattern--case3

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



Results and Discussion (15)

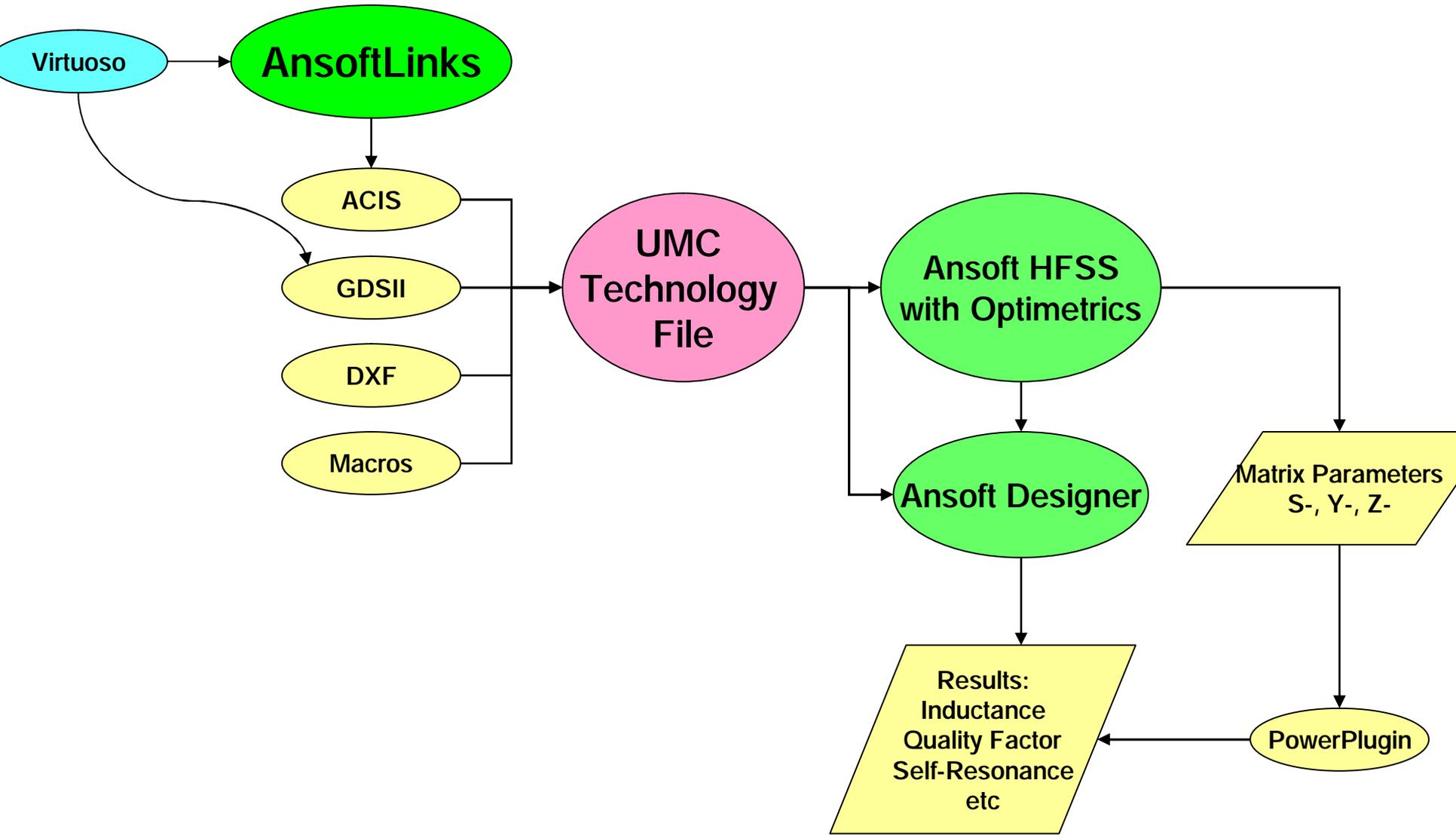
- Deep-trench pattern--case3



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EMDM Flow



AnsoftLink for Virtuoso

The image shows a screenshot of the Ansoft software interface. At the top, a menu bar includes 'Tools', 'Design', 'Window', 'Create', 'Edit', 'Verify', 'Connectivity', 'Options', 'Route', 'Ansoft', 'Q4_App', and 'Help'. A dropdown menu is open under 'Ansoft', listing options: 'Write ANF (V4 Lay)', 'Draw Layout Extent', 'Write ANF (V2)', and 'Launch Ansoft Links'. Below this, two windows are visible: 'AnsoftLinks(TM): qvconew.anf' and '3D Modeler - qvco_original'. The 'AnsoftLinks' window shows a complex circuit layout with various layers and nets. The '3D Modeler' window shows a 3D model of the same circuit, with a coordinate system and various parameters like 'Abs. [microns]', 'X', 'Y', 'Z', 'Rad', 'Ang', and 'Snap To' options. A large orange arrow points from the 'Launch Ansoft Links' menu item to the 'AnsoftLinks' window. Another large orange arrow points from the 'AnsoftLinks' window to the '3D Modeler' window. A white box with black text is overlaid on the bottom right of the 'AnsoftLinks' window, containing the text 'Easier than Cut & Paste'.

Tools Design Window Create Edit Verify Connectivity Options Route Ansoft Q4_App Help

Ansoft

- Write ANF (V4 Lay)
- Draw Layout Extent
- Write ANF (V2)
- Launch Ansoft Links

AnsoftLinks(TM): qvconew.anf

3D Modeler - qvco_original

Abs. [microns]

- X -106.60385207037
- Y 280.03892031513
- Z 0
- Rad 299.643418361732
- Ang 110.840584580348

Snap To: Vertex Grid Other...

Easier than
Cut & Paste

AnsoftLinks(TM), Copyright(C) 1999-2002 Ansoft Corporation (-4.1,-274.5)

Ansoft Q3D Extractor Version 5.0.04 Copyright 1984-2002 Ansoft Corporation

Other Use of HFSS in IC design

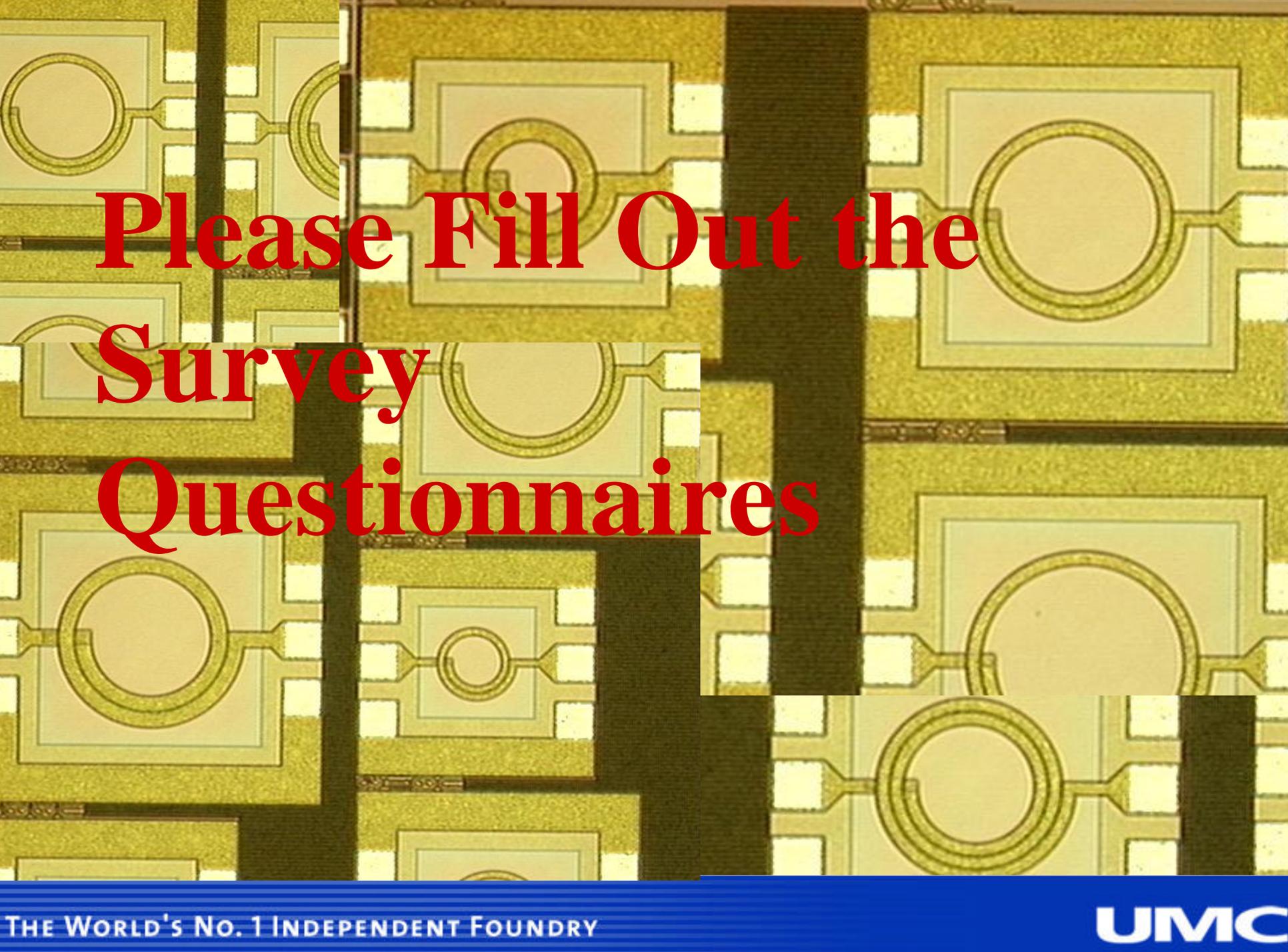
- With UMC EMDM:
 - Model extraction on Interconnection
 - Cross Talk analysis in RF or High Speed Digital IC
 - Capacitor: MIM, MOM (fringing)
 - Package Modeling for the IC Design
 - Internal Antenna Design
 - EM analysis RFIC with PCB

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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**