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Using Superposition Principle and Edge Current Model to Compute Impedance of Coil in Logging Tool

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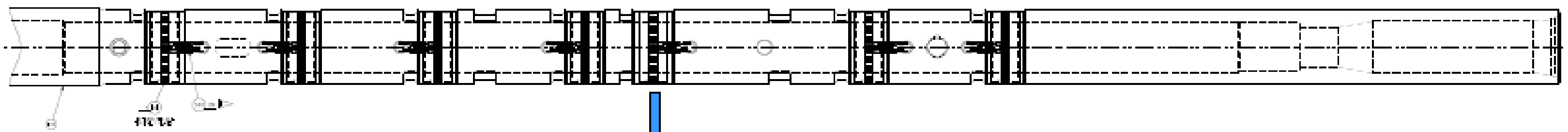
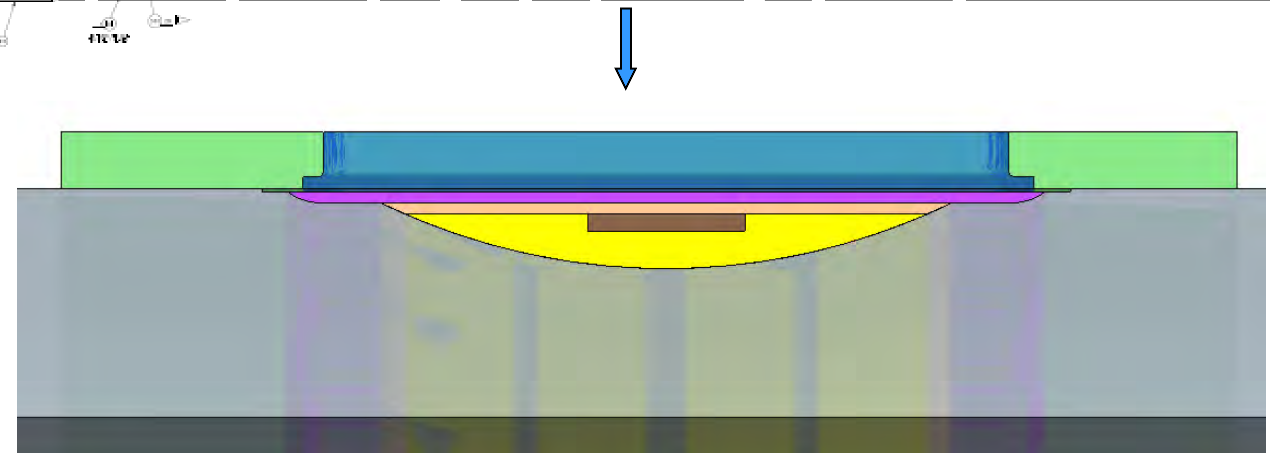
Outline

- Introduction to antenna configuration
- COMSOL model building
  - Edge model for self impedance R,L
    - Alternating TX-RX for self inductance
    - Superposition for AC resistance correction
  - Stray C computation

Antenna under study

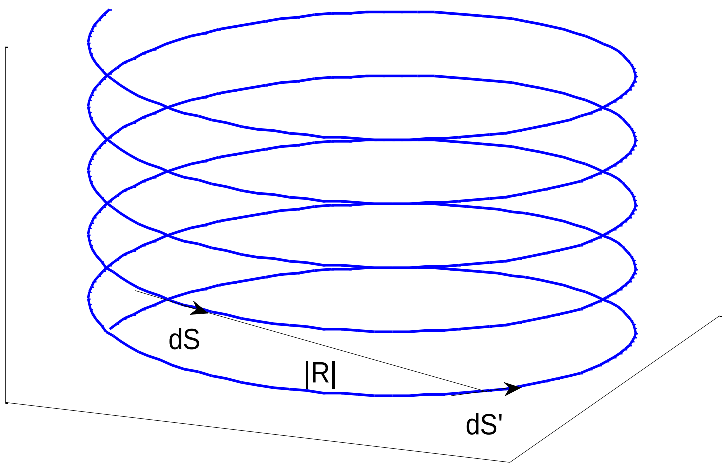
- Resistivity logging tool consists of antenna array, and it has 5 transmitters and 2 receivers (T,T,T,R,R,T,T).

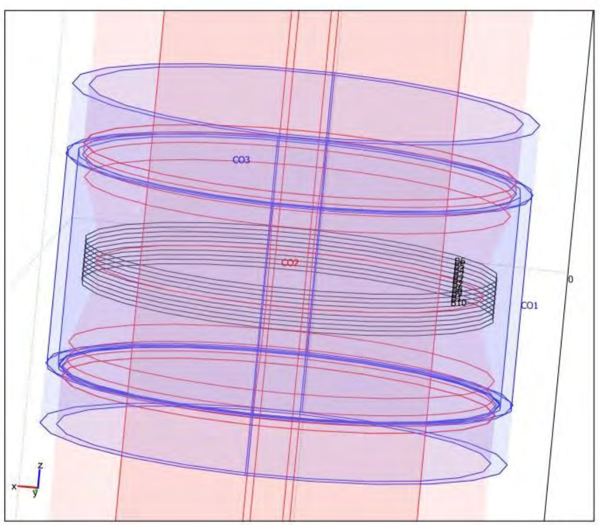




- Grey: collar, steel;
- Blue: shield, steel;
- Yellow and orange: fiberglass composite
- Brown: coil wire

How to Build Edge Model to compute Z11





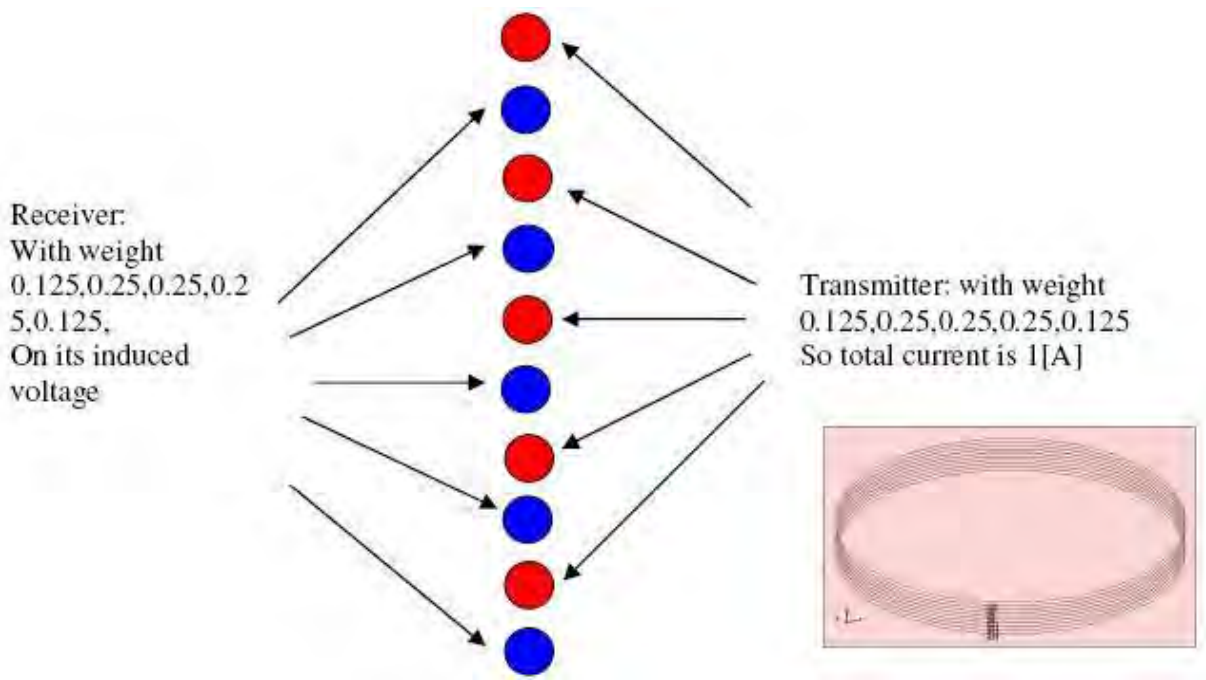
3D structure around coil

- Neumann formula for low frequency:

$$L = \frac{\mu}{4\pi} \int_C \int_{C'} dS \cdot dS' / |R|$$

- For AWG 18(d=1mm), skin depth is 0.1mm and 0.046mm at 400 kHz and 2 MHz.
- R can be zero for self inductance computation
- Analytical solution for coil in air is available, but not for with 3D collar and shield
- Difficult to mesh for thin wire at high frequency
- Use Edge to model thin wire with small skin depth

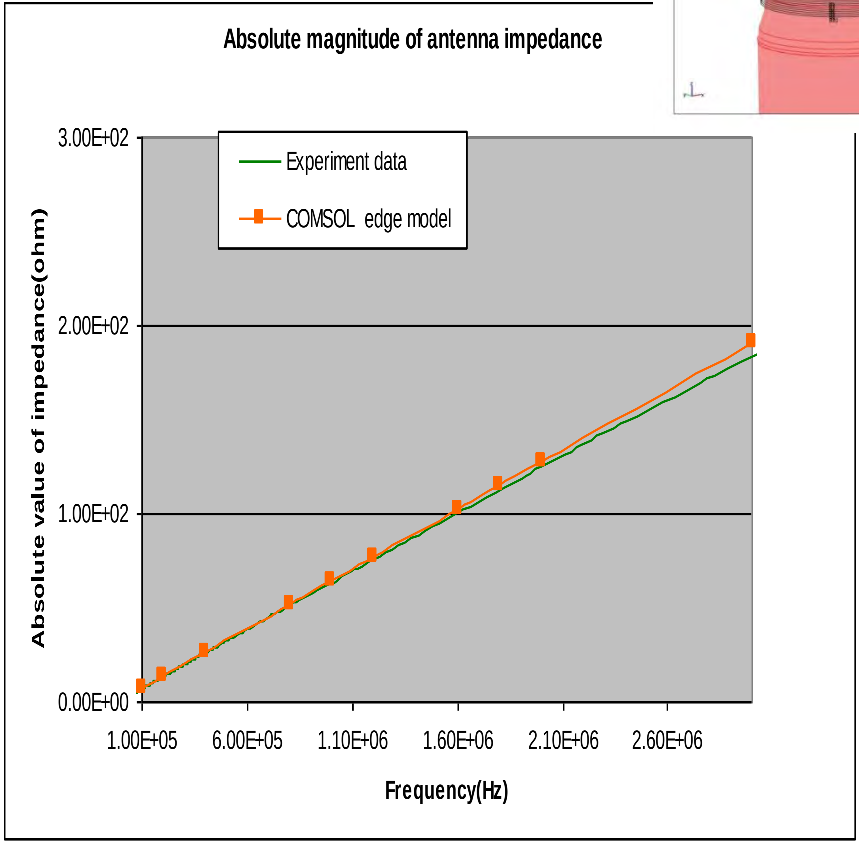
Alternating Source and Field Configuration to accurately model self-impedance



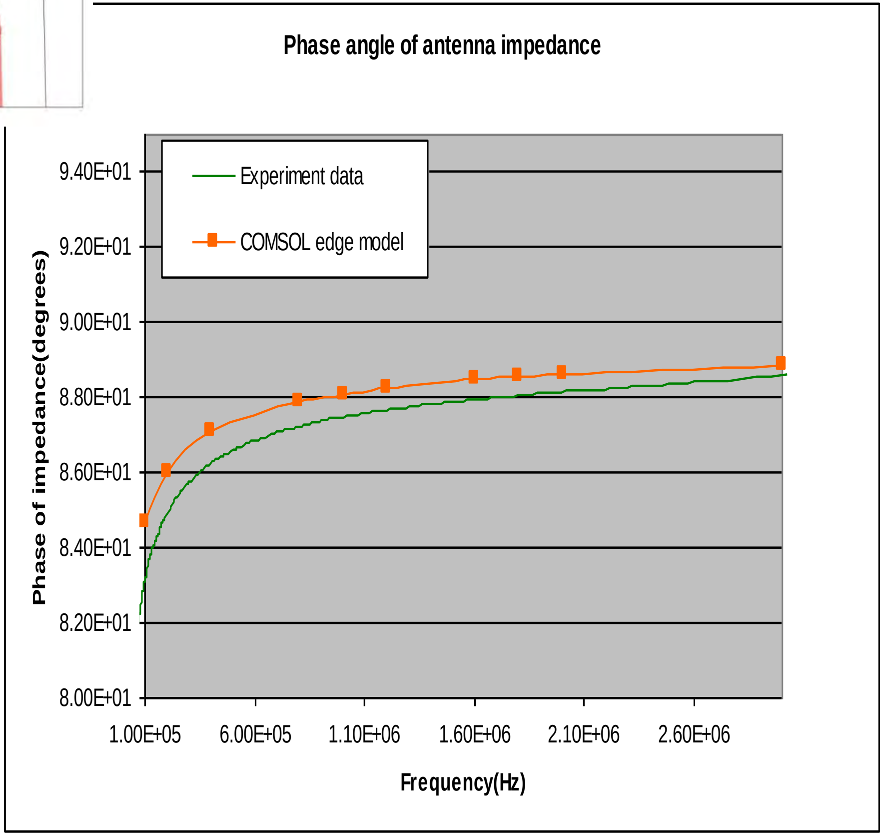
	Z11 (@2MHz) in ohm
Model (without alternating)	3.61+i*169.39
Model (alternating)	3.56+i*107.29
Experimental results	3.54+i*101.34

Comparison with measurement with collar

|Z| for unshielded ARC



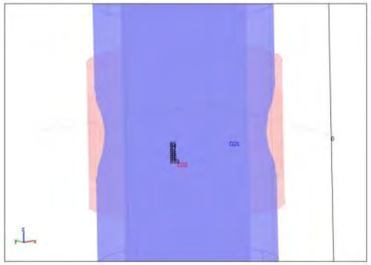
Z phase for unshielded ARC

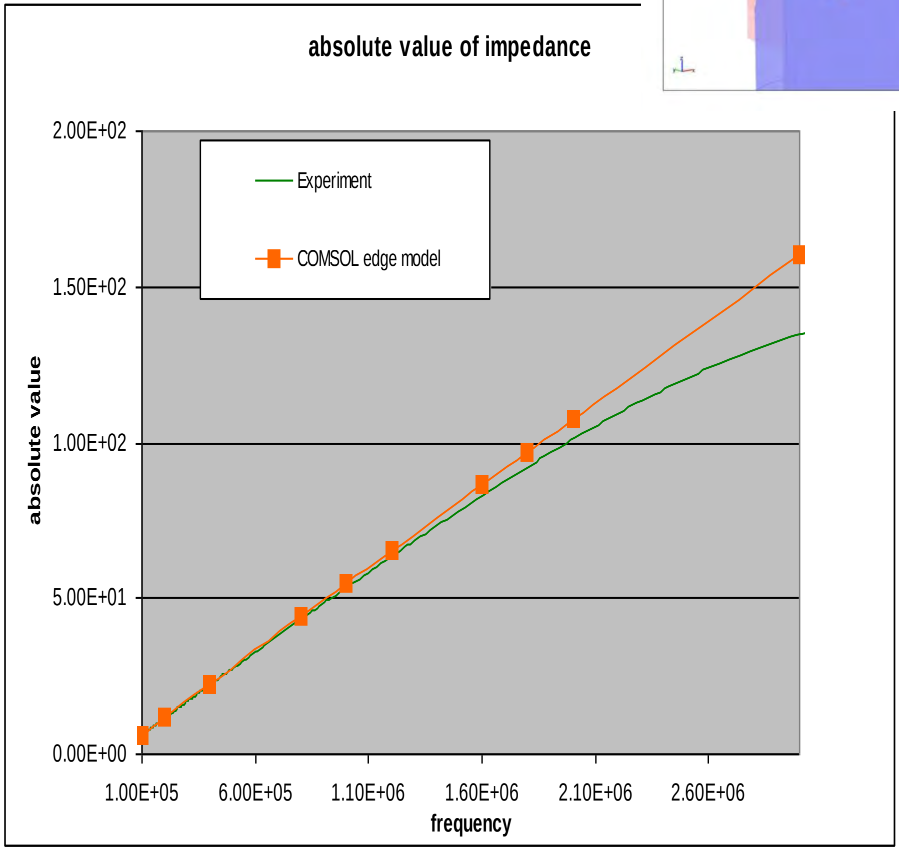


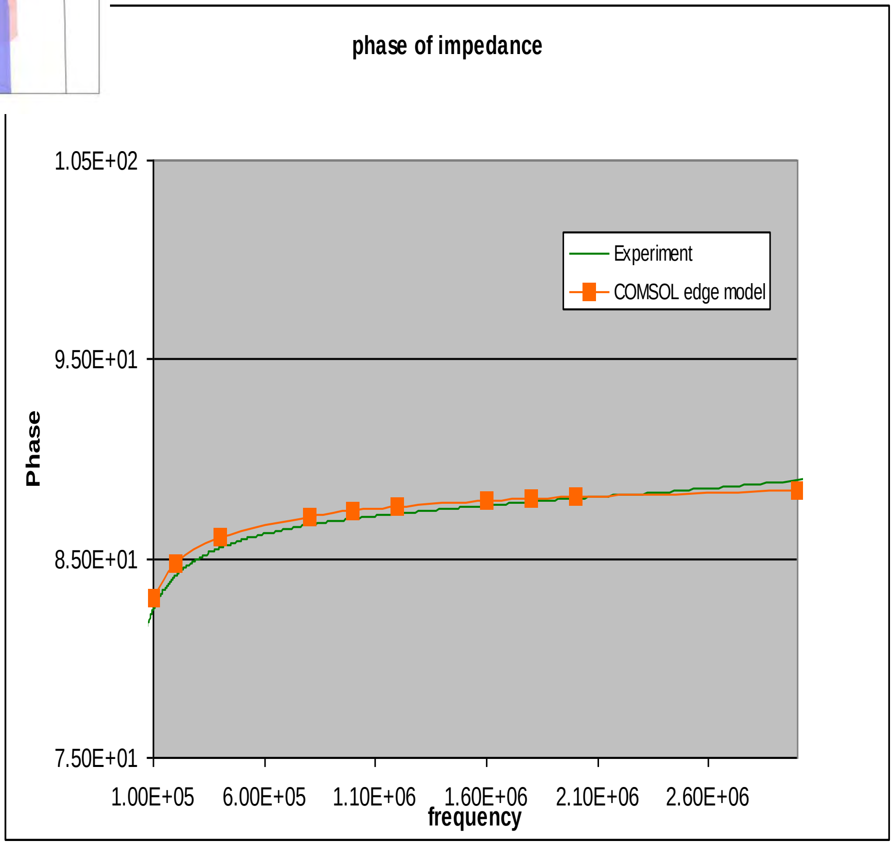
Comparison with measurement with collar and shield

|Z| for shielded tool

Z phase for shielded tool







Superposition for modified Z

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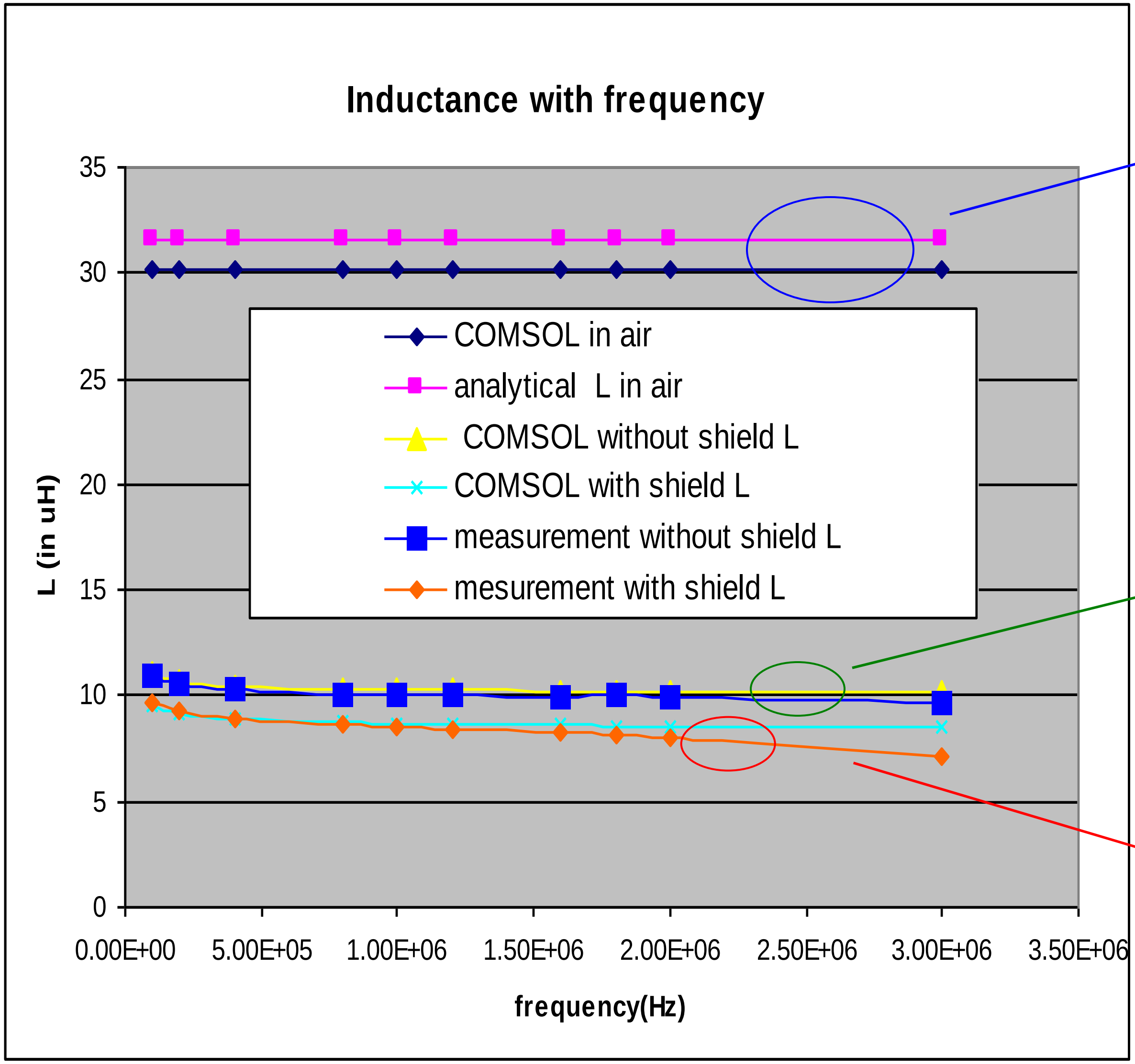
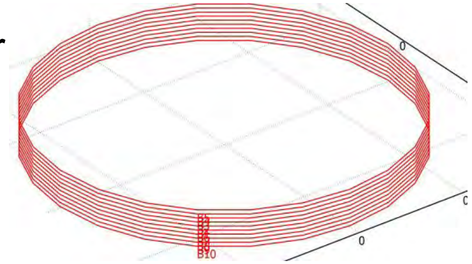
Freq.	COMSOL Model		Analytical	
	Z_{COLLAR}	Z_{AC} (air)	Z_{AC} (air)	
(MHz)	(Ω)	(Ω)	(Ω)	
0.4	1.54 + i22.29	0.0032+i76.03	0.49+i77.28	
2.0	3.56 + i107.30	0.08+i378.78	1.03+i386.42	
Freq.	Final	Measurement	Zcollar– Z_{MEAS}	
	Z_{TOTAL}*	Z_{MEAS}	Mag.	Phase
(MHz)	(Ω)	(Ω)	(Ω)	(°)
0.4	2.03 + i23.54 (23.63∠ 85.08°)	22.43 ∠85.54°	0.09	0.51
2.0	4.51 + i114.94 (115.03∠87.75°)	101.4∠88.02°	5.96	0.08

$$^{*}Z_{TOTAL}=Z_{COLLAR}-Z_{AIR\_COMSOL}+Z_{AIR-ANALYTIC}$$

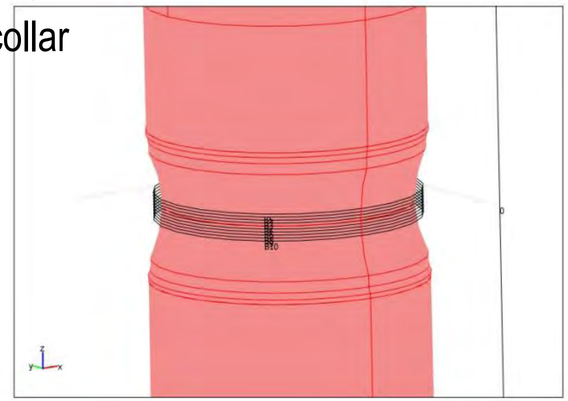
Comparison with measurement: coil in air, with or without shield



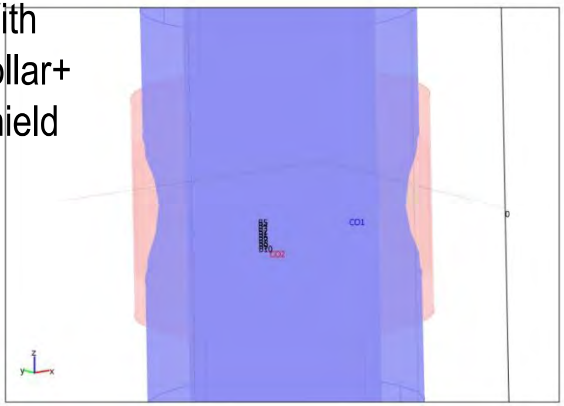
In air



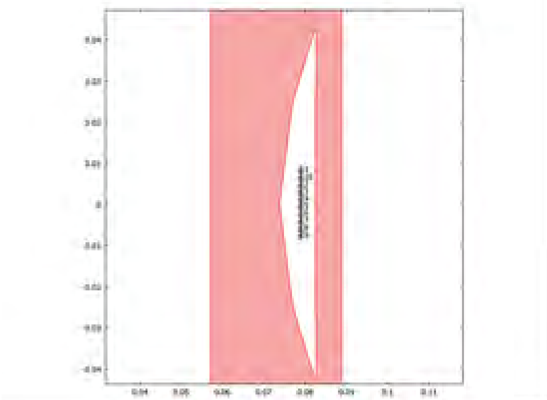
With collar

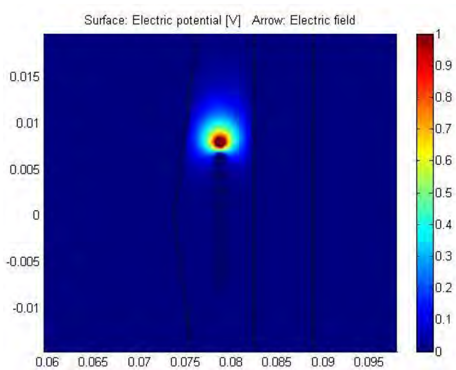


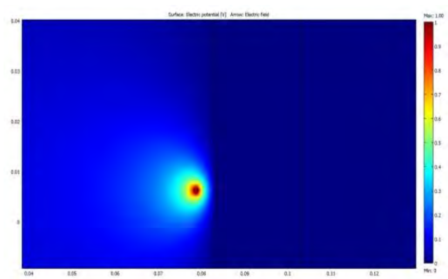
With collar+ shield

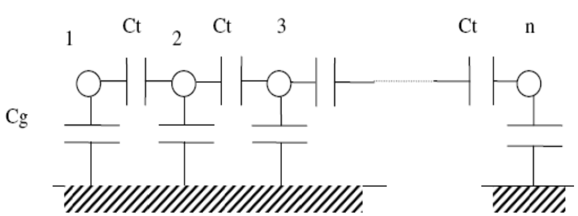


Stray Capacitance C Modeling







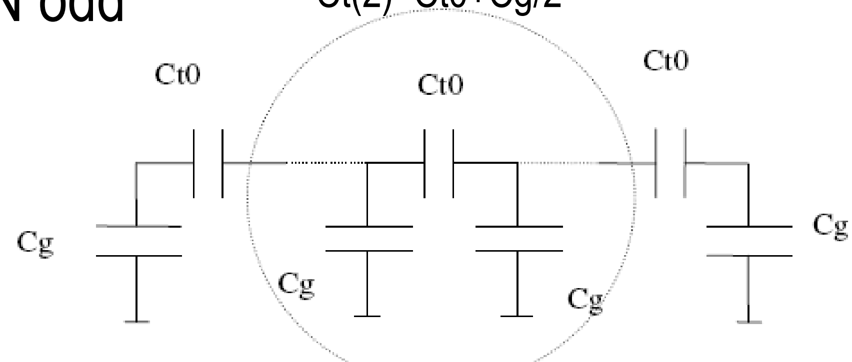


C=[0.0159	0.0075	0	0	0
0	0	0	0	0;
0.0075	0.0198	0.0073	0	0
0	0	0	0	0;
0	0.0073	0.0198	0.0073	0
0	0	0	0	0;
0	0	0.0073	0.0198	0.0073
0	0	0	0	0;
0	0	0	0.0073	0.0198
0.0073	0	0	0	0;
0	0	0	0	0.0073
0.0198	0.0073	0	0	0;
0	0	0	0	0
0.0073	0.0198	0.0073	0	0;
0	0	0	0	0
0	0.0073	0.0199	0.0073	0;
0	0	0	0	0
0	0	0.0073	0.0199	0.0075;
0	0	0	0	0
0	0	0	0.0075	0.0161] nF;

Iterative Computation of Capacitance

N odd

Ct(2)=Ct0+Cg/2

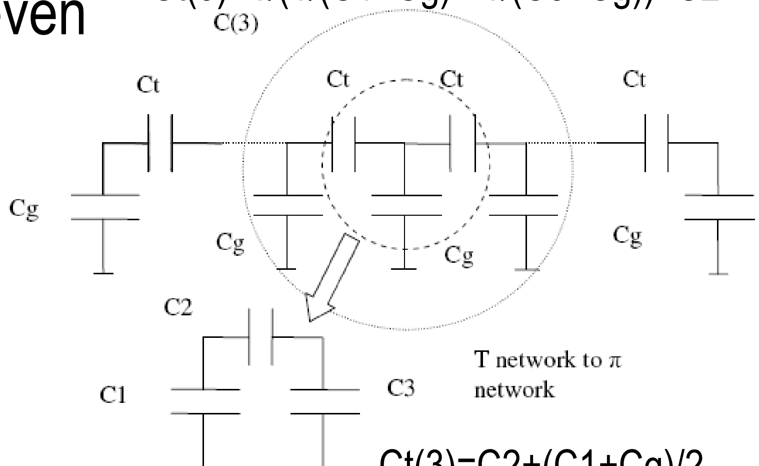


Ct(n)=1/(1/Ct0+1/Ct0+1/C(n-2))+Cg/2

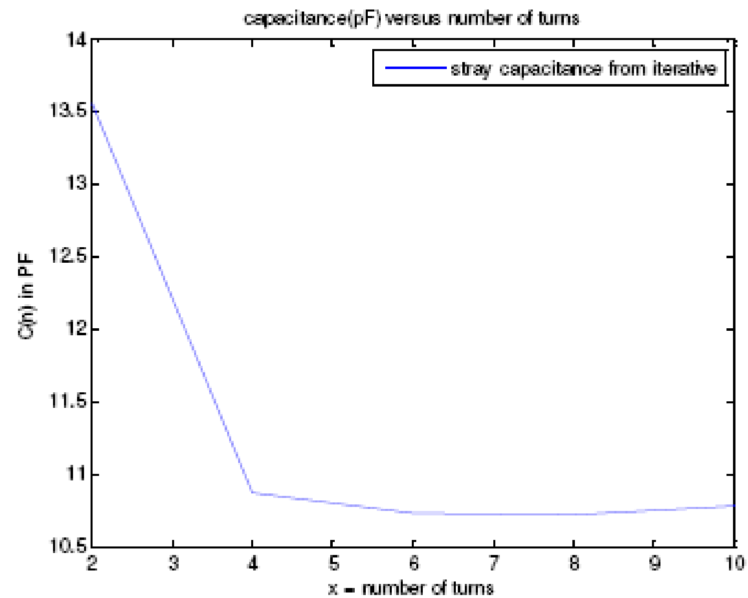
Ct(2)

N even

Ct(3)=1/(1/(C1+Cg) +1/(C3+Cg))+C2



Ct(3)=C2+(C1+Cg)/2

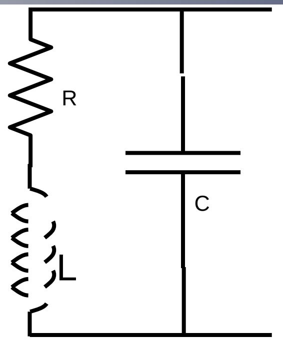


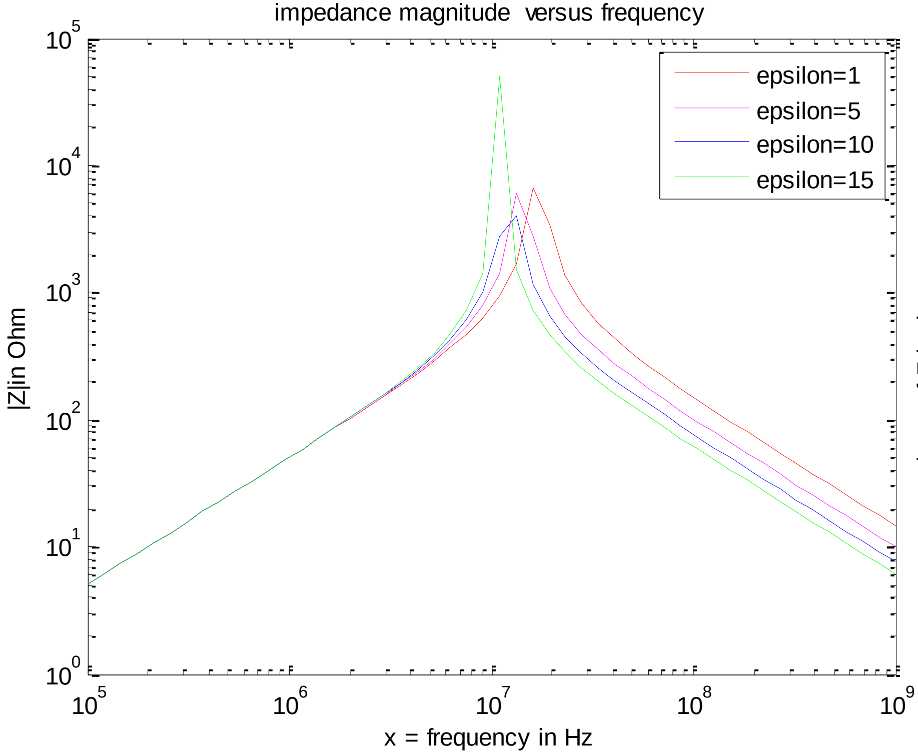
The overall capacitance in pF versus number of turns.

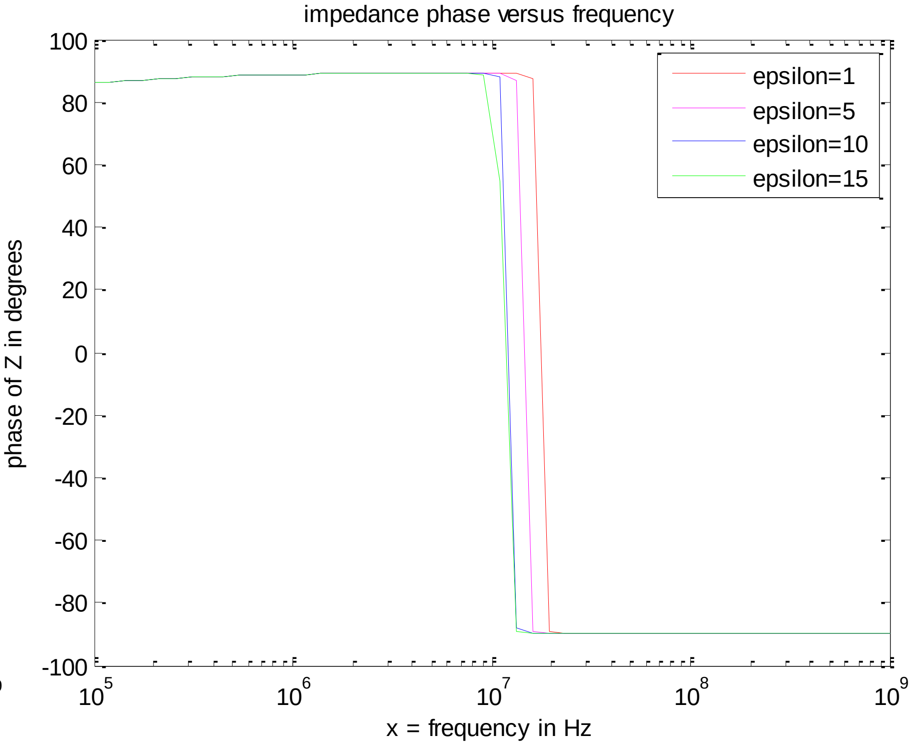
Converged C=10.78pF in air

To compute Resonant frequency and Z

$$Z = 1/\left(1/\left(R + j\omega L\right) + j\omega\varepsilon_r C\right)$$







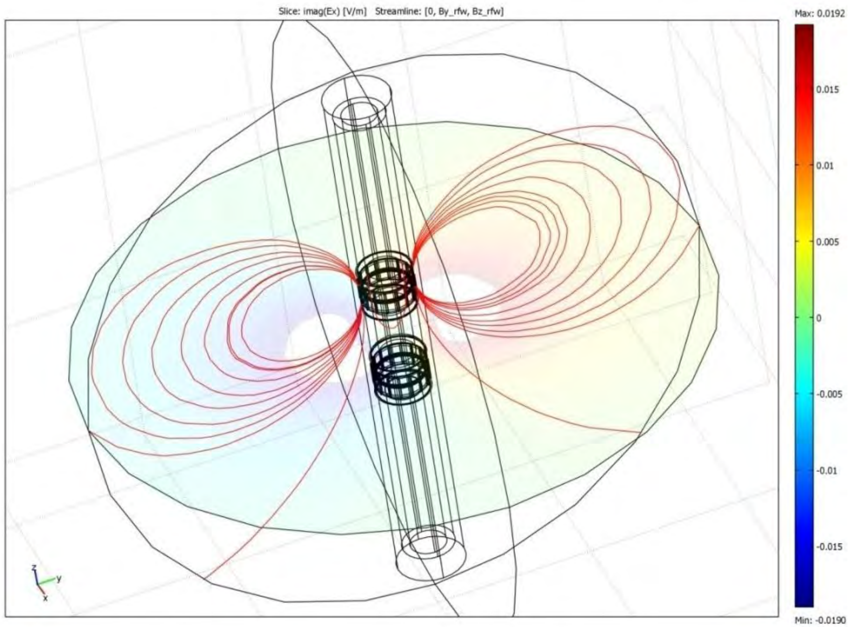
Conclusion

- An new approach of modeling the input impedance modeling is created using COMSOL, and it matches the measurement result well, it can model the high frequency thin wire coil accurately
- COMSOL can answer some challenging problems in electromagnetic sensor development

Thank you

Questions?

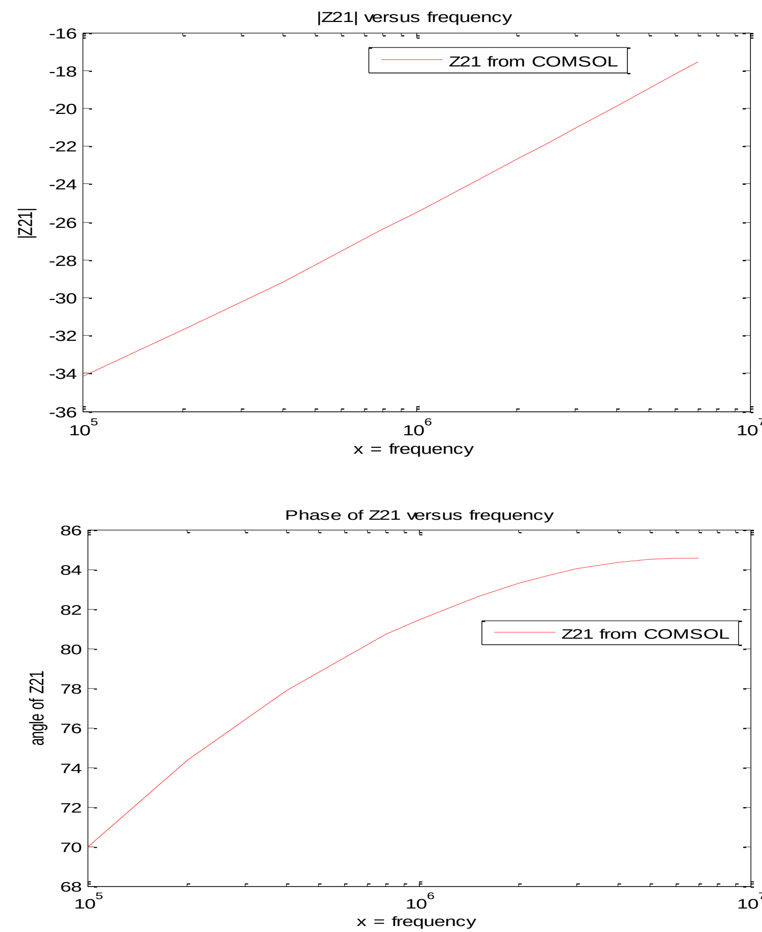
Array response



For antenna in air (no collar and shield),From Grover's book, M=0.18uH.

COMSOL Z21=1.637023e-4+i*0.453795 ohm at 400k, M=imag(Z21)/omega=0.18056 uH.

Model is validated by analytical result.



Z21 in 1 pair of TX and RX