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A Methodology for the Simulation of MEMS Spiral Inductances used as Magnetic Sensors

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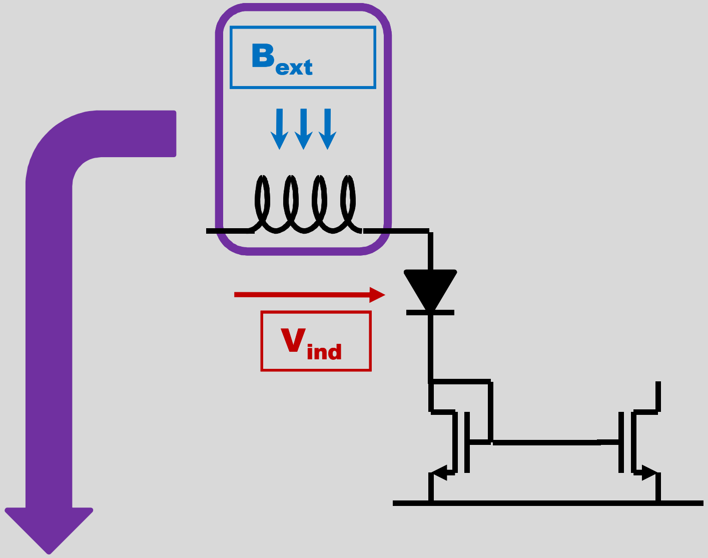
Why Comsol ?

- An example of circuit application with an inductor…



Geometry
Induced voltage
Inductance value
?

Integrated MEMS inductance with CMOS technologies

Parameterized
FEM simulations

Outline

☐ Model description

☐ Script architecture

☐ Simulation results and applications

☐ Conclusions

Model description

- ☐ Equation model overview
- ☐ System geometry

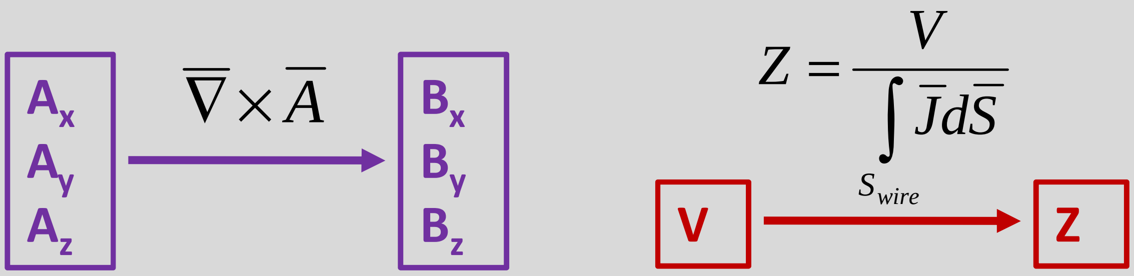
Equation model overview

- ❑ **Time Harmonic electromagnetism module**

$$\overline{\nabla}\bullet\left(\left(j\omega\sigma-\omega^{2}\varepsilon_{0}\varepsilon_{r}\right)\overline{A}+\left(\sigma+j\varepsilon_{0}\varepsilon_{r}\right)\overline{\nabla}V\right)=0$$

$$\left(j\omega\sigma-\omega^{2}\varepsilon_{0}\varepsilon_{r}\right)\overline{A}+\overline{\nabla}\times\left(\frac{1}{\mu_{0}\mu_{r}}\overline{\nabla}\times\overline{A}\right)+\left(\sigma+j\varepsilon_{0}\varepsilon_{r}\right)\overline{\nabla}V=0$$

- ❑ **Output quantities**

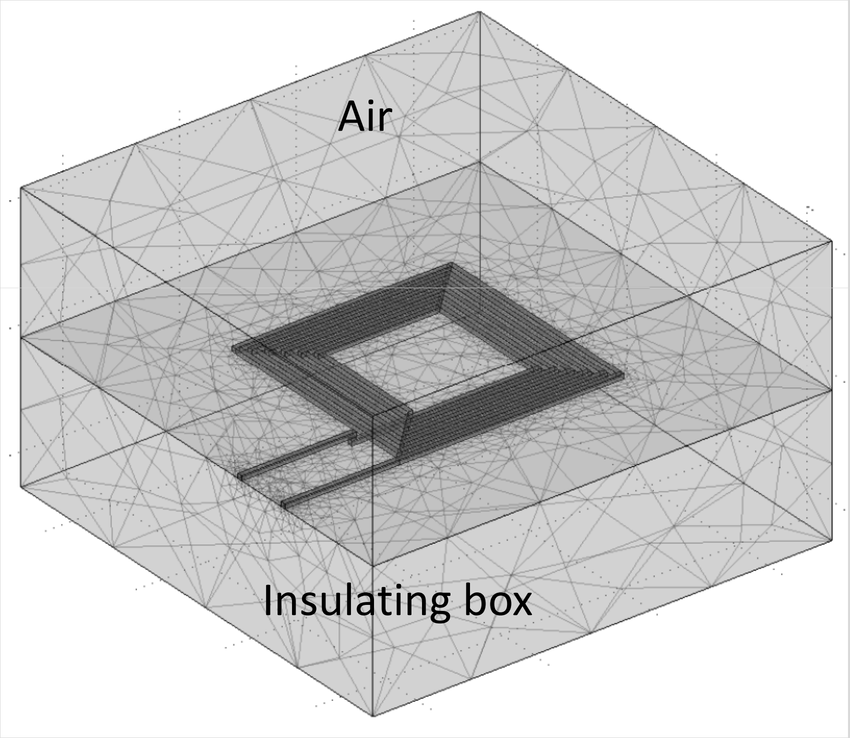


$$Z=\frac{V}{\int_{S_{wire}}\overline{J}d\overline{S}}$$

- ❑ Model description
- ❑ Script architecture
- ❑ Simulation results and applications
- ❑ Conclusions

System geometry

- ☐ FEM geometry: spiral shape



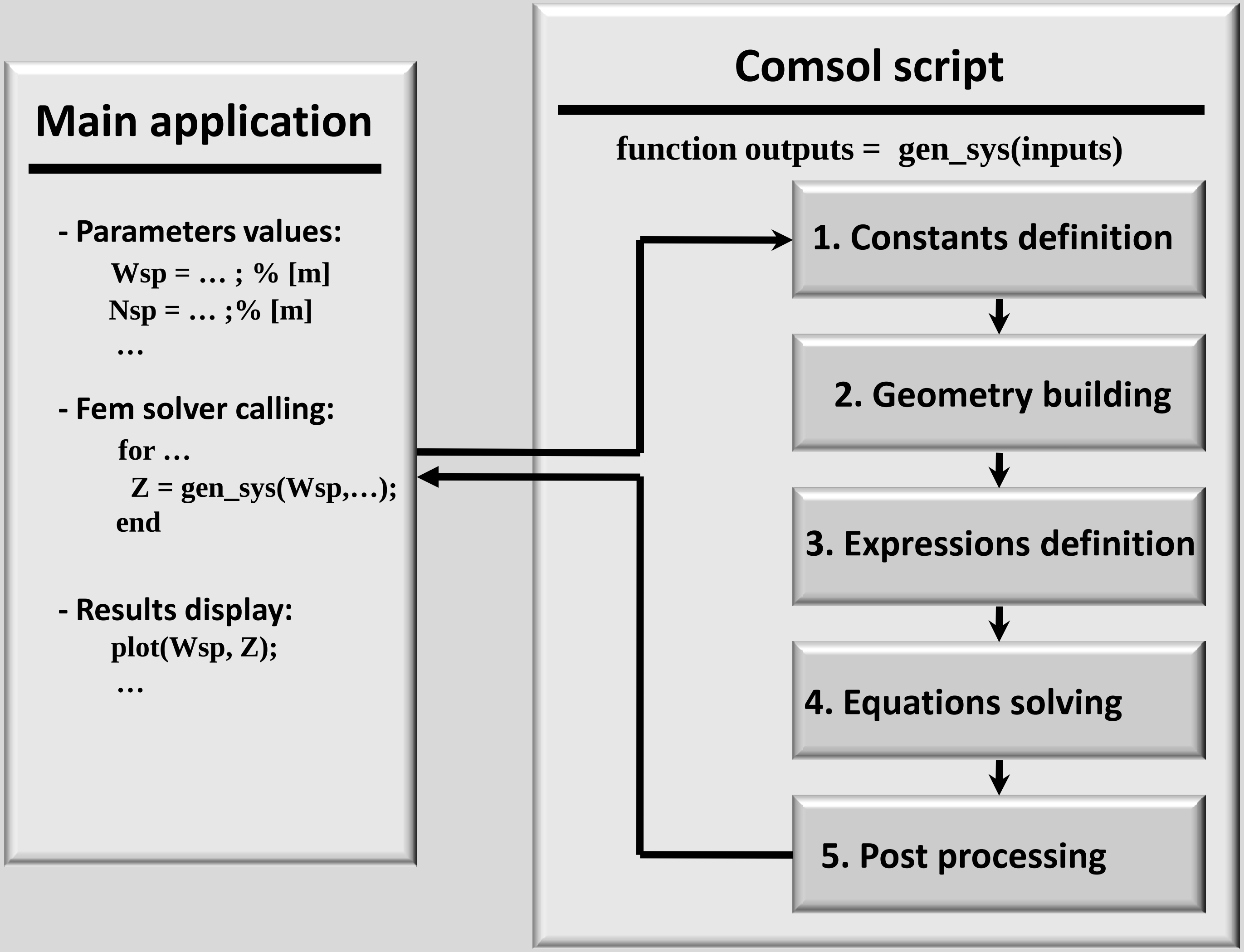
- ☐ Parameters

Wire width: Ww
Wire thickness: Hw
Inner square length: Lc
Number of turns: Nsp

Script architecture

- ☐ Program hierarchy
- ☐ Programming steps
- ☐ Index numbering problem

Program hierarchy



Main application

- Parameters values:

```
Wsp = … ; % [m]
Nsp = … ;% [m]
…
```

- Fem solver calling:

```
for …
  Z = gen_sys(Wsp,…);
end
```

- Results display:

```
plot(Wsp, Z);
…
```

Comsol script

```
function outputs =  gen_sys(inputs)
```

1. Constants definition
2. Geometry building
3. Expressions definition
4. Equations solving
5. Post processing

- ☐ Model description
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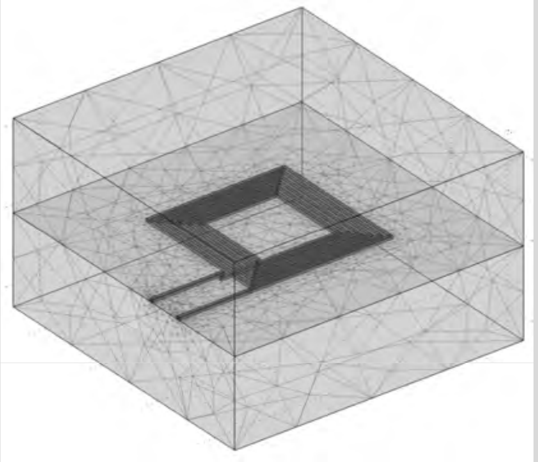
Index numbering problem

❑ Manual boundary condition assignment example

Condition 1: electric ground
Condition 2: continuity
Condition 3: electric insulation



More than 200 boundary faces!!

- ➢ Manual filling of boundary index array

```
bnd.ind = [3,3,3,3,2,2,2,2,3,3,2,2,1,2,2,2,2,2,2,2,2, ...];
```

index=4 index=13 index=19

☹ Need of manual assignment update when geometry changes

☹ High risk of programming errors

❑ Model description
❑ Script architecture
❑ Simulation results and applications
❑ Conclusions

Index numbering problem

❑ Automatic boundary condition assignment example

Condition 1: electric ground
Condition 2: continuity
Condition 3: electric insulation

$$X_{M,i} = \frac{\iiint x_i dx_1 dx_2 dx_3}{\iiint dx_1 dx_2 dx_3}$$

- ➢ Boundaries mass center X_M calculation

$\mathrm{Index}_4 = \mathrm{getIndex}(X_{M4});$ $\mathrm{Bnd.ind}(\mathrm{index}_4) = 3;$
$\mathrm{Index}_{13} = \mathrm{getIndex}(X_{M13});$ $\mathrm{Bnd.ind}(\mathrm{index}_{13}) = 1;$
$\mathrm{Index}_{19} = \mathrm{getIndex}(X_{M19});$ $\mathrm{Bnd.ind}(\mathrm{index}_{19}) = 2;$

☺ **No need of assignment update when geometry changes**

☺ **Low risk of programming errors**

- ➢ Same way for subdomains conditions

Results and applications

- ☐ Input parameters
- ☐ Impedance calculation
- ☐ AC magnetic field detection
- ☐ Metallic particles detection

Input parameters

❑ Geometry

Wire width:	Ww = 20 µm
Wire thickness:	Hw 20 µm
Inner square length:	Lc = 100 … 500 µm
Number of turns:	Nsp = 1 … 6

❑ Physics

Wire conductivity (Cu):	σ_w = 59.6 MS/m
Air permittivity:	$\varepsilon_{air} = \varepsilon_0$ F/m
Oxyde permittivity (SiO_2):	$\varepsilon_{ox} = 3.9\varepsilon_0$ F/m
Inward current:	I_{inward} = 10 µA
Input frequency:	f_{sys}= 1 MHz

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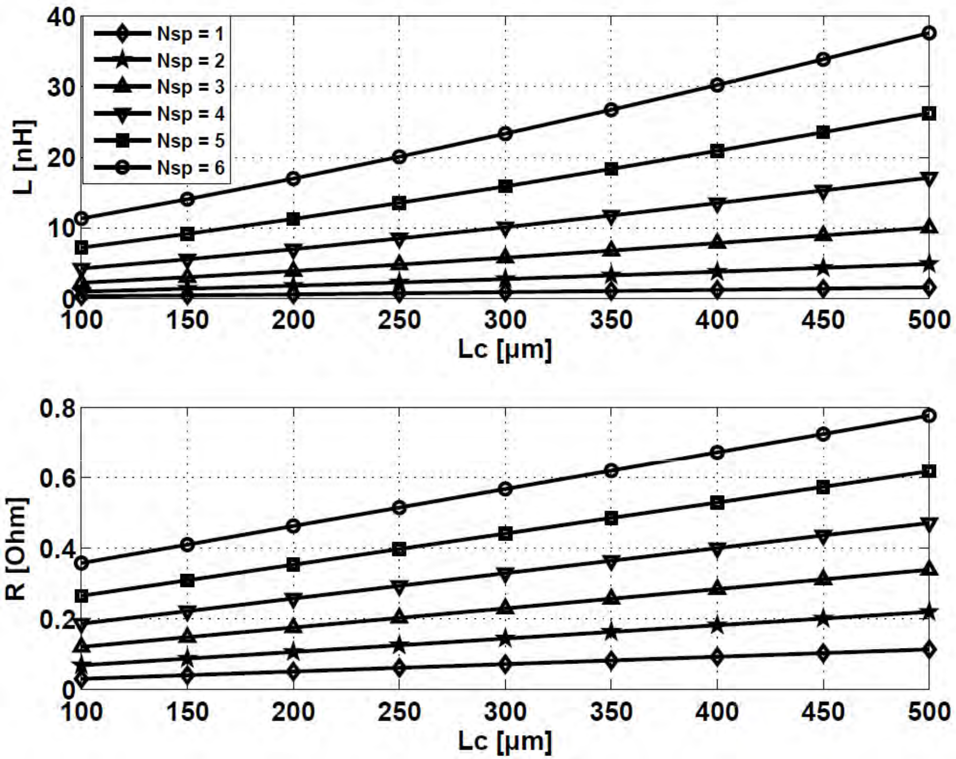
Impedance calculation



$$W_{mag} = \iiint_{\Omega} w_{emqav} \, dV$$

$$\downarrow$$

$$L = \frac{2W_{mag}}{I^2_{inward,eff}}$$

$$Z = \frac{V_{ab}}{I_{inward}}$$

$$\downarrow$$

$$L = \frac{\mathrm{Im}(Z)}{\omega}$$

$$R = \mathrm{Re}(Z)$$

Wire width:	**Ww = 20 µm**
Wire thickness:	**Hw 20 µm**
Inner square length:	**Lc = 100 … 500 µm**
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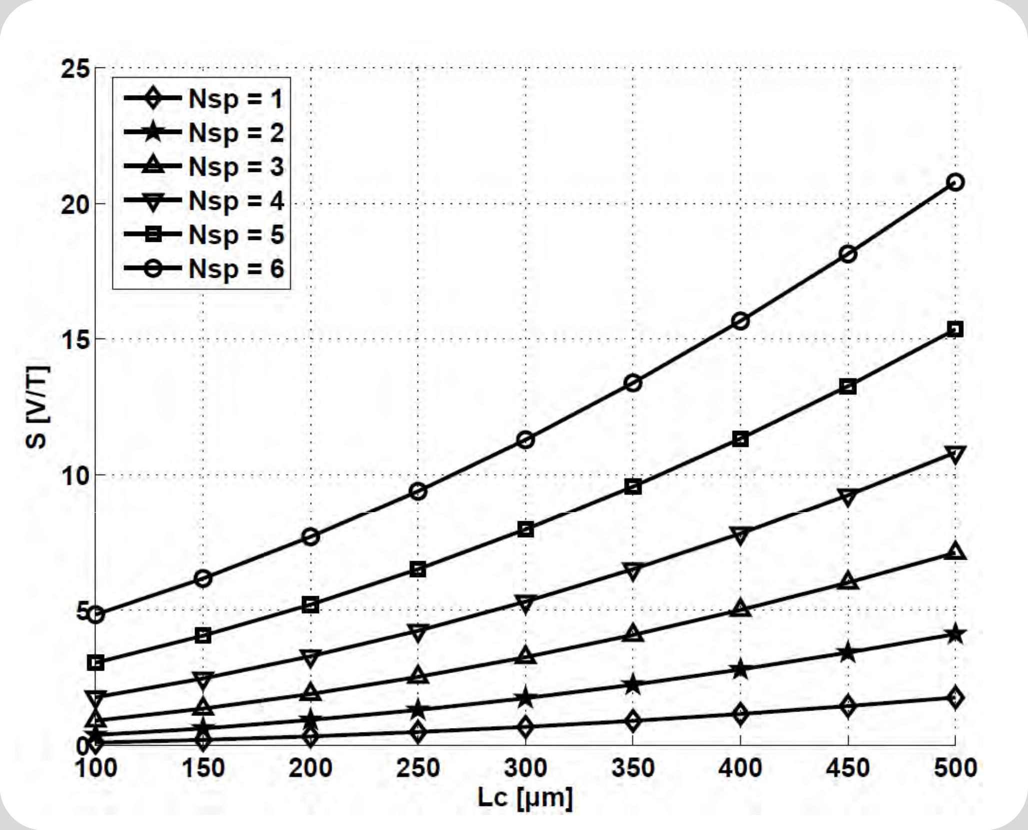
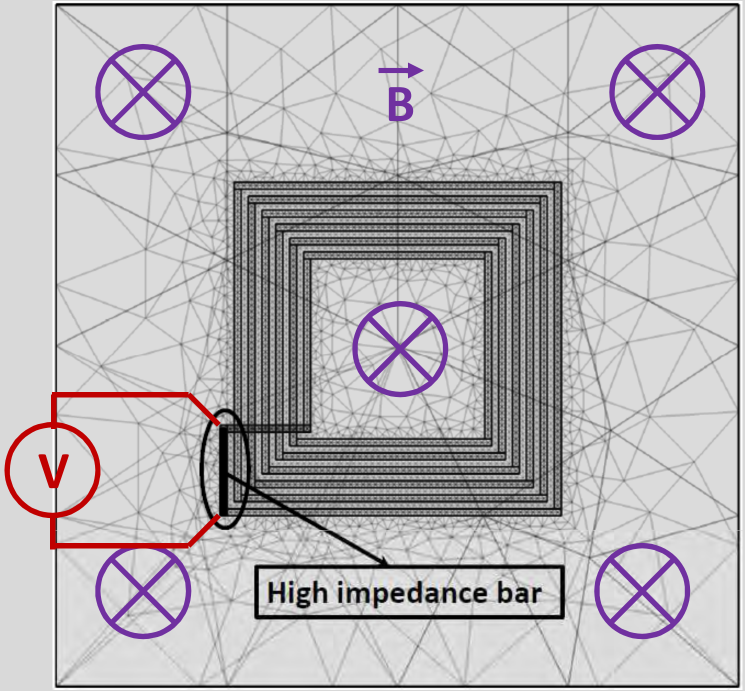
- ❑ **Model description**
- ❑ **Script architecture**
- ❑ **Simulation results and applications**
- ❑ **Conclusions**

AC magnetic field detection





$B = B_{amp}\sin(\omega t)$

54 simulations performed !

- ❑ Model description
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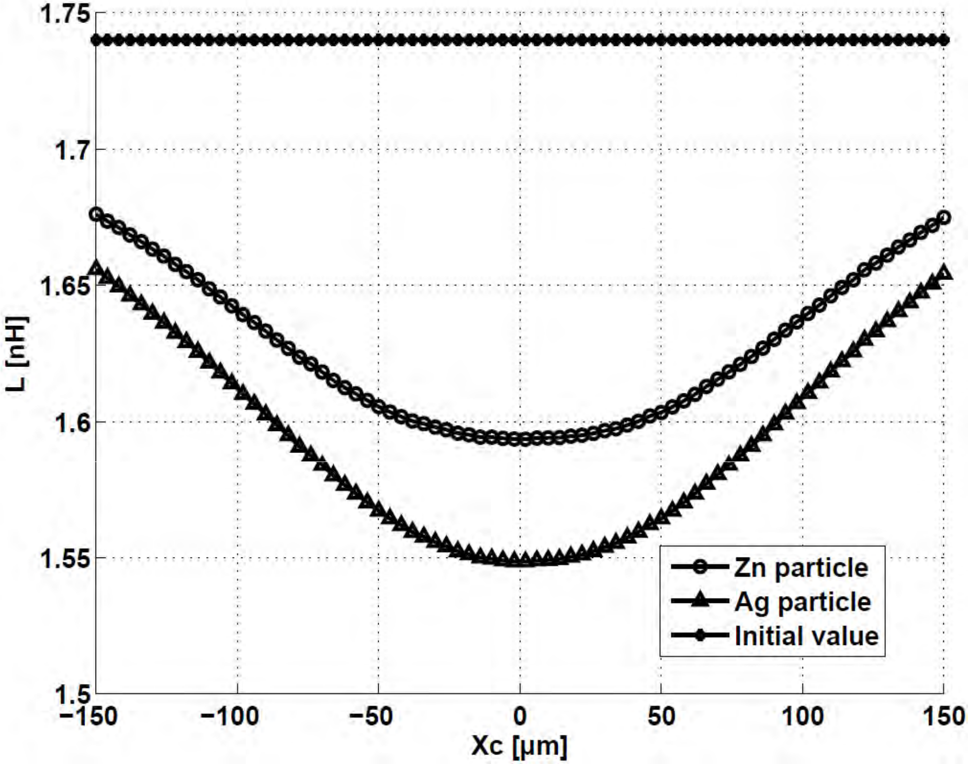
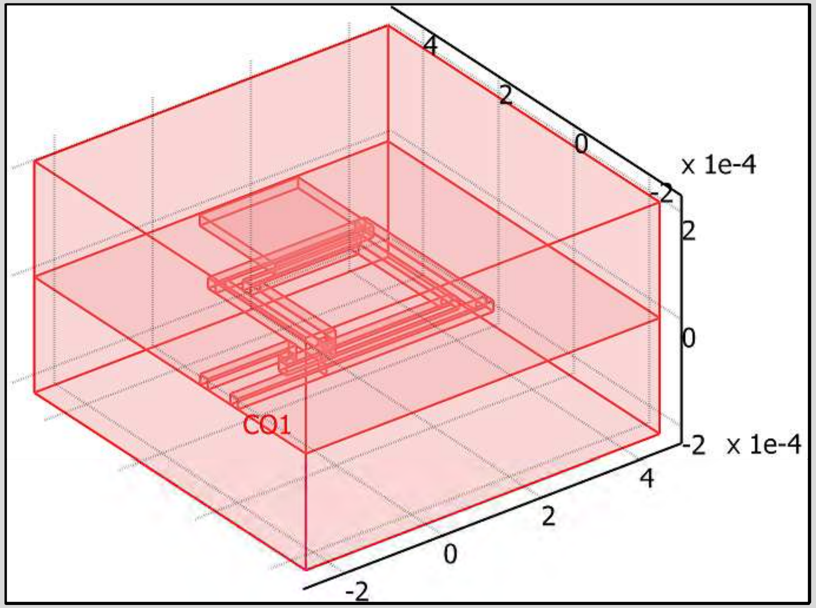
Metallic particles detection





About 90 simulations !!

- ☐ Model description
- ☐ Script architecture
- ☐ Simulation results and applications
- ☐ Conclusions

Conclusions

☐ Parameterized oriented simulations

- Large campaign of simulations
- Automatic generation of the finite element sctructure

☐ Inductances simulations

- Easy interpreting results
- Efficiency of the electromagnetic module in several applications

Thanks for your attention