ADVANCED APPLICATIONS OF AN AUTOMATED GENERATIVE TOOL FOR MEMS DESIGN BASED ON COMSOL MULTIPHYSICS

Bolognini Francesca
University of Cambridge
Cambridge, UK

COMSOL 2011 - Stuttgart, October 27th 2011

UNIVERSITY OF CAMBRIDGE

Outline

- Introduction: Computational Design Synthesis (CDS) Tools
- Obstacles in the development of CDS tools
- Investigation on how to integrate evaluation packages (COMSOL) in the automated generation of designs
- Example of applications of the tool to MEMS design

Overview of Computational Design Synthesis

- Computational Design Synthesis:

Synthesis methods aim at facilitating designers' task through the automated generation of optimal solutions (optimally directed design alternatives).

Objectives:

- Promote lateral thinking to boost innovation
- Guarantee better search of the design space in fast effective way
- Generate muticriteria design archives for investigating complex performance trade-offs
- Reduce design time and costs

…

- Mainly academic applications, no routine use in industry yet.
- 'Open issues' (Cagan et al., 2005) in the research field.

A comprehensive review: 'Formal Engineering Design Synthesis' (Antonsson and Cagan, 2001)

Obstacles to the Development of CDS Methods

- Possible obstacles to the development/use of CDS methods in common practice:
- Difficulty in implementing methods for multi-domain knowledge tasks
- Difficulty in handling real case studies (scalability)
- Difficulty in integrating external analysis and simulation

- The idea behind this work:
- Is it possible to push the use of CDS methods a step further than what has been done in the past introducing sophisticated analysis and simulation?
- Is it possible to set-up an evaluation module that can scale-up to industrial applications?

- How: advanced integration of COMSOL in a CDS tool.

Computational Synthesis Tools Architecture

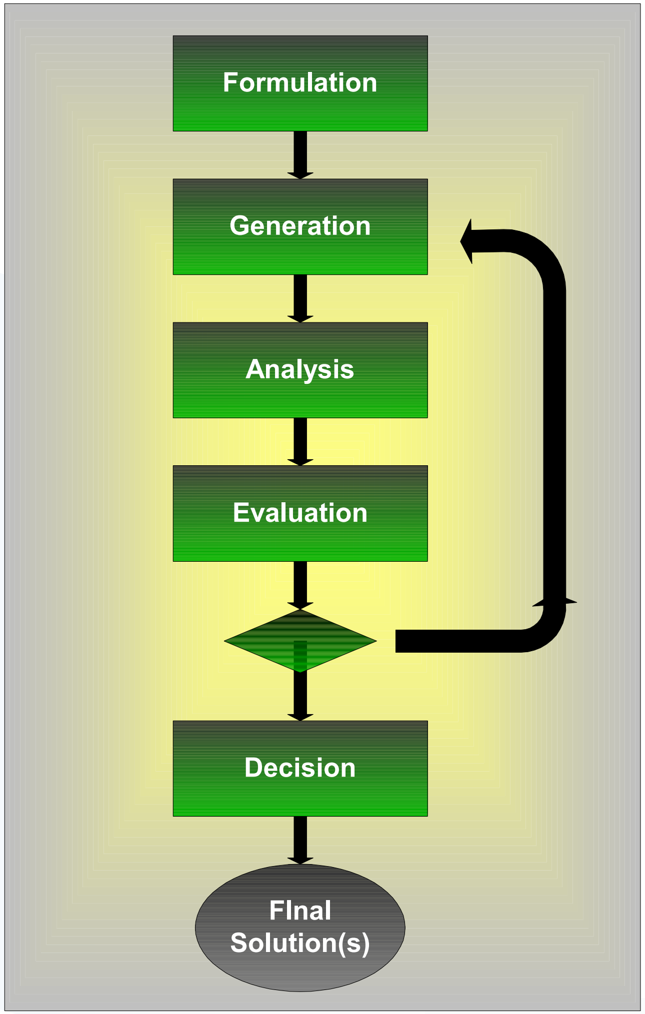
MODULES

•Definition of the task (formulation)
  Mathematical representation

•Automated design generation
  Search method and design rules

•Analysis and Evaluation
  Integrated multiphysics simulation for quantitative evaluation of design performances (COMSOL)

•Decision
  Pareto optimality criteria



COMSOL Integration

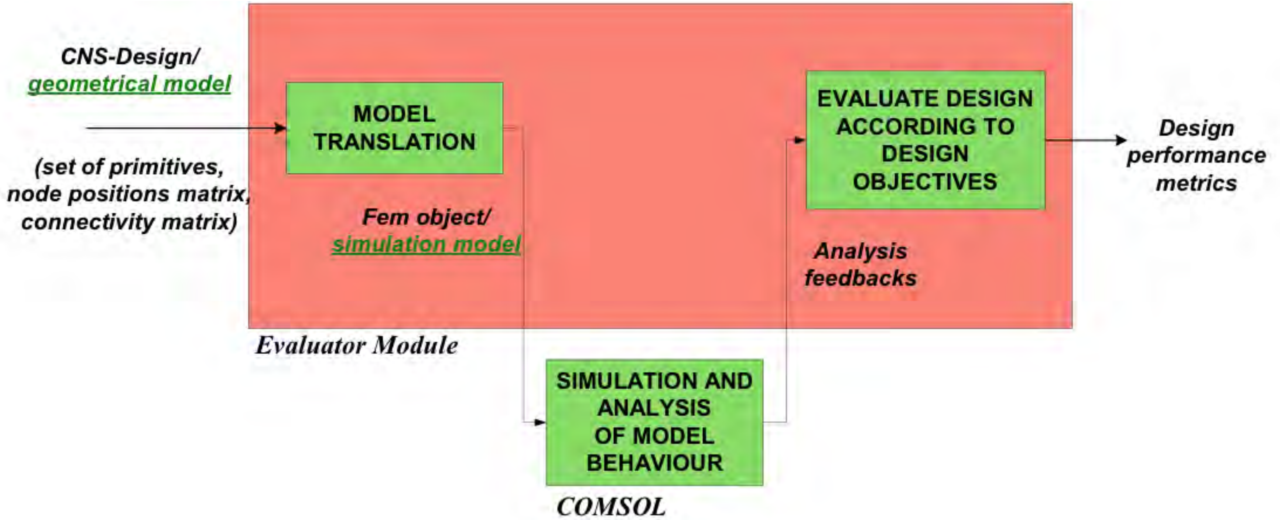
- Translating generated design objects (geometry, constraints, boundary conditions…) into COMSOL objects

- Visualise simulation behaviour automatically every time a new design in generated

- Pass feedbacks resulting from analysis to the search.

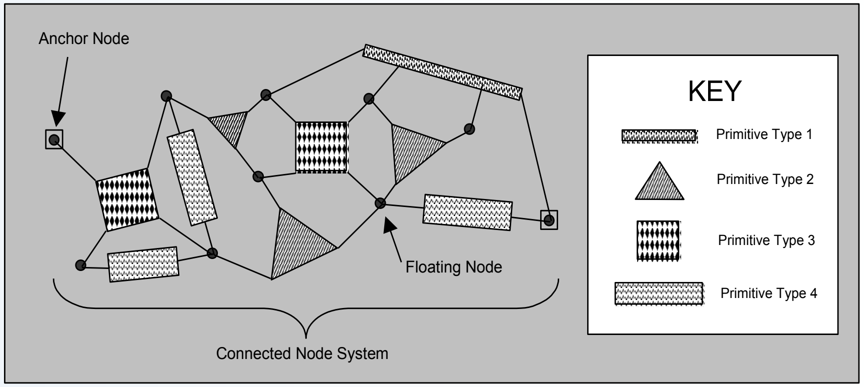
Use of COMSOL from API (Matlab): functions called from Matlab command line.

Translation of geometrical model into simulation model



- Connected Node System Object (matrix based):
  - primitives
  - nodes

- Matrix based:
  - Nodelist
  - Connectivity



Geometrical Model / Simulation Model

CNS DESIGN OBJECT

Design.Primitives

Design.Primitives {i}. Name
Design.Primitives {i}.Parameters
Design.Primitives {i}.MaxInstance
Design.Primitives {i}.MinInstance
Design.Primitives {i}.ParamLimtis

Design.NodeDefinitions

Design.NodeDefinitions {ti}. Name
Design.NodeDefinitions {ti}.Properties
Design.NodeDefinitions {ti}. CanAdd
Design.NodeDefinitions {ti}.CanRemove
Design.NodeDefinitions {ti}.PropsChangeable
Design.NodeDefinitions {ti}. PropLimits
Design.NodeDefinitions {ti}. MinConnects
Design.NodeDefinitions {ti}. MaxConnects

Design.Connectivity

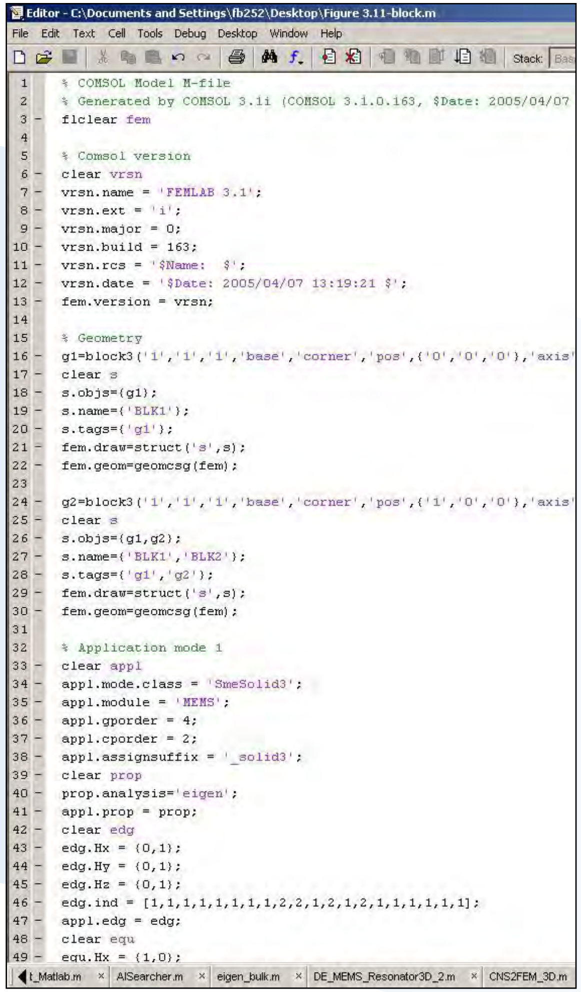
Primitives →, Nodes ↓

$$\begin{bmatrix} 1 & 0 & 1 & \dots \\ 2 & 1 & 0 & \dots \\ \dots & \dots & \dots & \dots \\ 0 & 2 & 2 & \dots \end{bmatrix}$$

Design.NodeList

Type ¦ Coordinates →, Nodes ↓

$$\begin{bmatrix} t1 & x1 & y1 & \dots \\ t2 & x2 & y2 & \dots \\ \dots & \dots & \dots & \dots \\ tn & xn & yn & \dots \end{bmatrix}$$



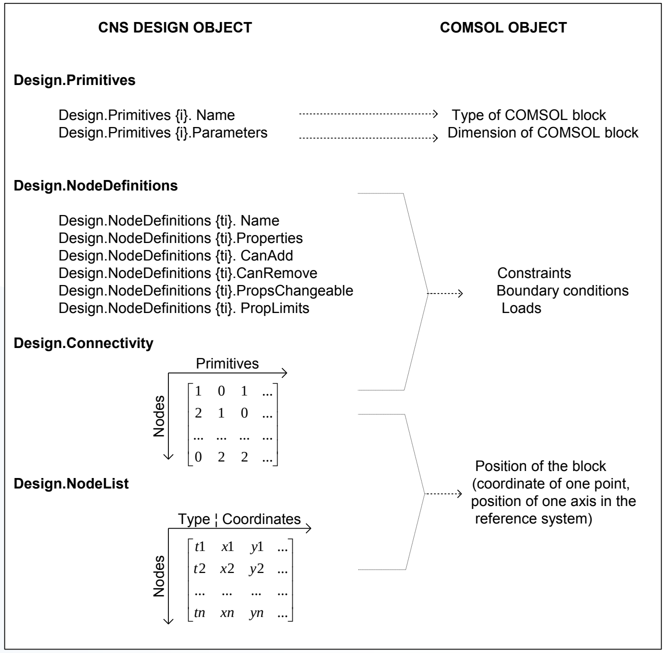

```
% COMSOL Model M-file
% Generated by COMSOL 3.1i (COMSOL 3.1.0.163, $Date: 2005/04/07
flclear fem

% Comsol version
clear vrsn
vrsn.name = 'FEMLAB 3.1';
vrsn.ext = 'i';
vrsn.major = 0;
vrsn.build = 163;
vrsn.rcs = '$Name:  $';
vrsn.date = '$Date: 2005/04/07 13:19:21 $';
fem.version = vrsn;

% Geometry
g1=block3('1','1','1','base','corner','pos',{'0','0','0'},'axis'
clear s
s.objs={g1};
s.name={'BLK1'};
s.tags={'g1'};
fem.draw=struct('s',s);
fem.geom=geomcsg(fem);

g2=block3('1','1','1','base','corner','pos',{'1','0','0'},'axis'
clear s
s.objs={g1,g2};
s.name={'BLK1','BLK2'};
s.tags={'g1','g2'};
fem.draw=struct('s',s);
fem.geom=geomcsg(fem);

% Application mode 1
clear appl
appl.mode.class = 'SmeSolid3';
appl.module = 'MEMS';
appl.gporder = 4;
appl.cporder = 2;
appl.assignsuffix = '_solid3';
clear prop
prop.analysis='eigen';
appl.prop = prop;
clear edg
edg.Hx = {0,1};
edg.Hy = {0,1};
edg.Hz = {0,1};
edg.ind = [1,1,1,1,1,1,1,1,2,2,1,2,1,2,1,1,1,1,1,1];
appl.edg = edg;
clear equ
equ.Hx = {1,0};
```



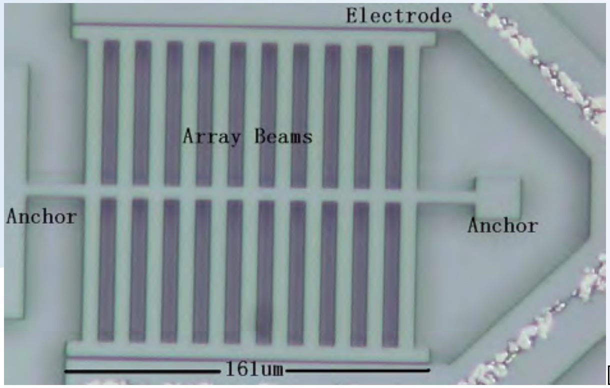
Translation of features: CNS OBJECT into COMSOL object

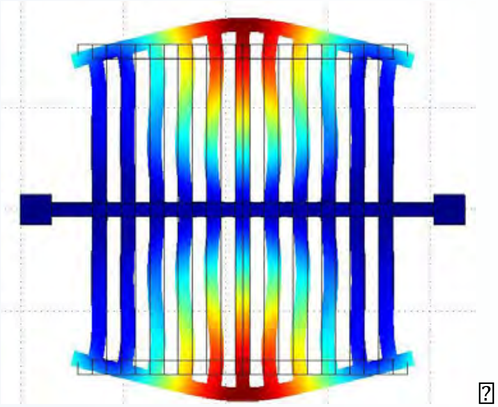
CNS OBJECT
(geometrical model)

COMSOL OBJECT (m.file)
(simulation model)

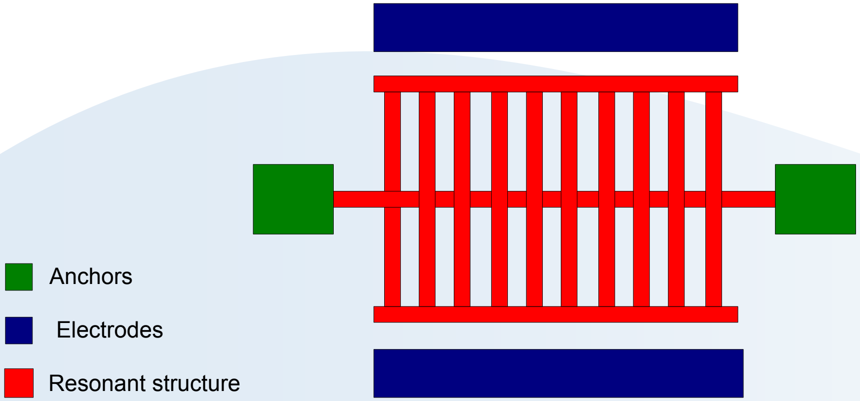
Complex Applications: Microresonators

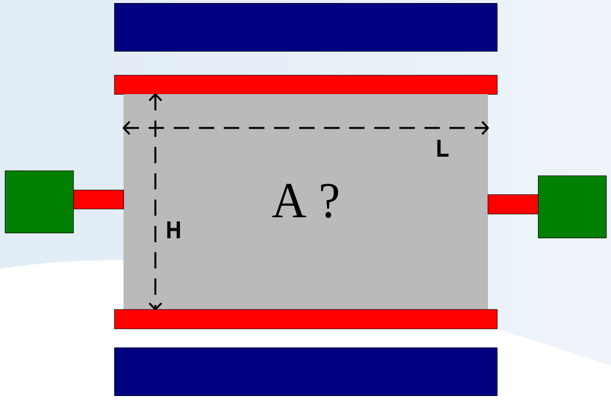
- A resonator is a device with vibratory natural response, actuated by electrically generated forces
- Microresonators have been often investigated using generative techniques (Fedder, Zhou)
- Microresonators have risen the interest of industry in last decade
- Sandwich resonators offer a complex design and a challenging task





Sandwich resonators





Sandwich resonator optimisation Model:

-Objectives:

- Minimum error in resonant frequency (target frequency 25MHz)
- Minimum motional resistance Rm
- Maximum quality factor Q

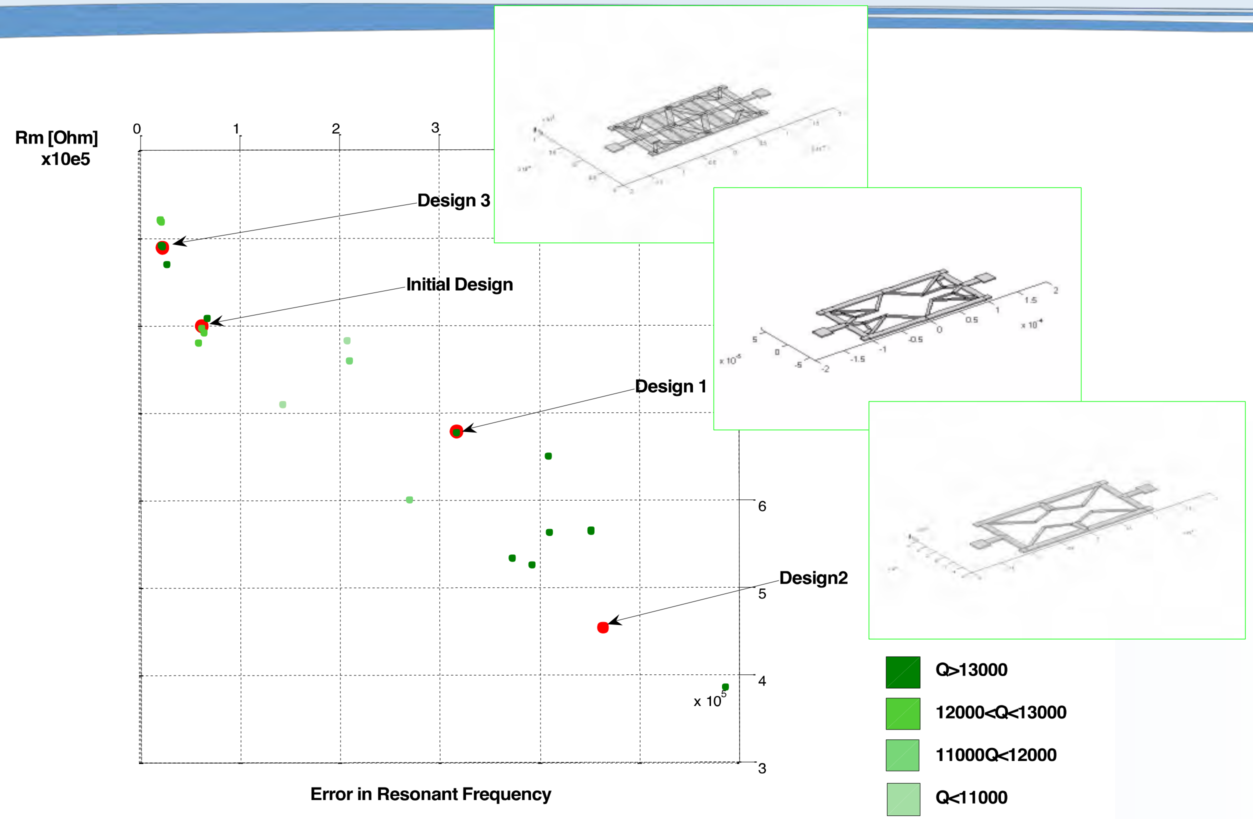
-Manufacturing constraints:

- Area A=LxH
- Minimum width of the beams and gap

-Design variables:

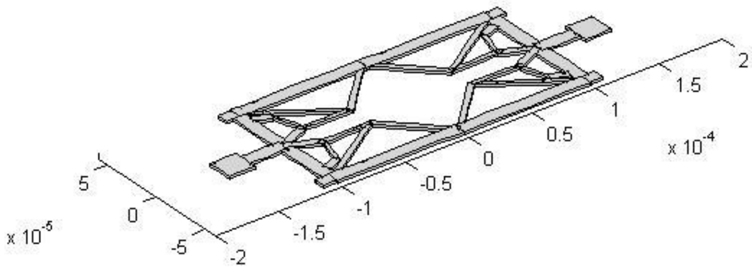
- Entire resonator topology and geometry in the area A=L x H

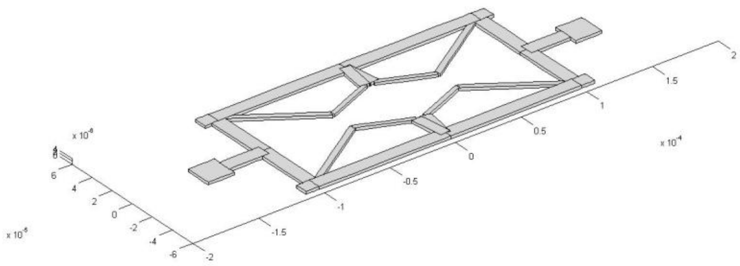
Sandwich resonators: Archive of Solutions

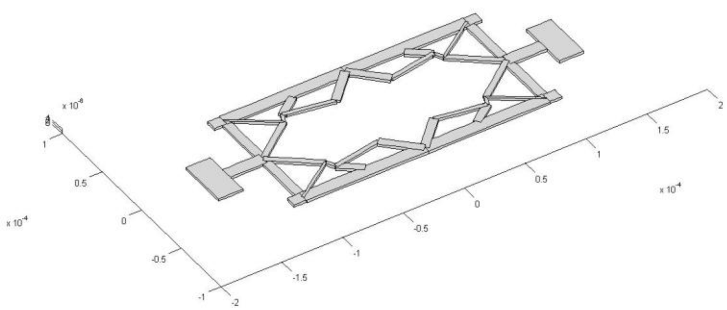


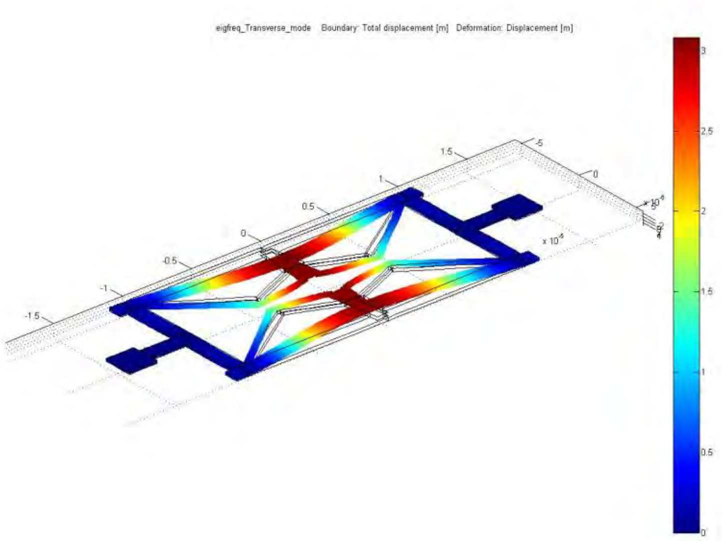
	Δf	R (KΩ)	1/Q
Solution1	3.178	679	7.24×10^{-5}
Solution 2	4.645	455	6.63×10^{-5}
Solution 3	0.22	889	6.63×10^{-5}
Hand Analysis (Initial Design)	0.62	800	7.68×10^{-5}

Sandwich resonators: Search Results









Conclusions

- This work has presented a particular use of COMSOL as a component of a CDS method.

- The successful results in obtaining innovative designs through the application of the method are also due to the introduction of COMSOL as part of the evaluation and simulation module.

- While COMSOL accuracy allowed precision of results, its flexibility allowed its direct and straightforward integration in the computational design process.

- This work confirms COMSOL uniqueness as an analysis and simulation package.

Thank you

The authors gratefully acknowledge the support of the UK Engineering and Physical Research Council (EPSRC) and Philips.