Calibration, Sensitivities and Robustness analysis of a angular rate sensor

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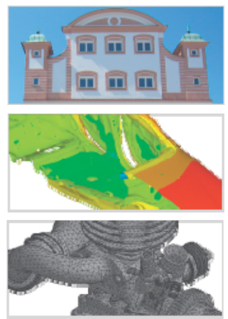
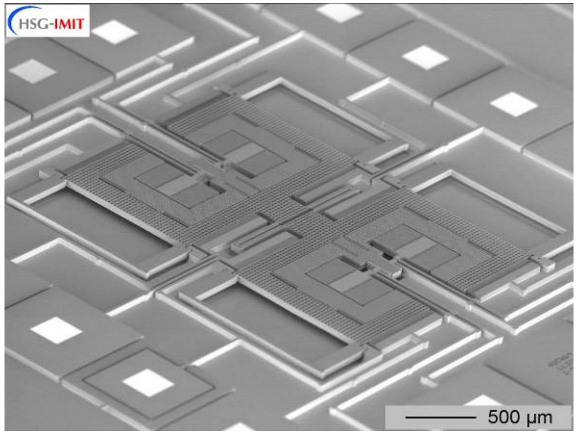
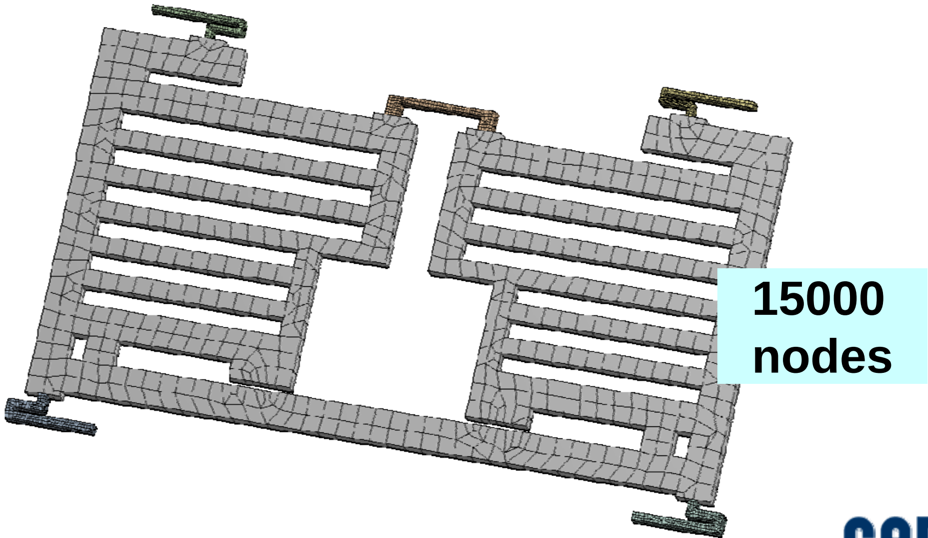
CADFEM GmbH



Optimization of a sensor structure

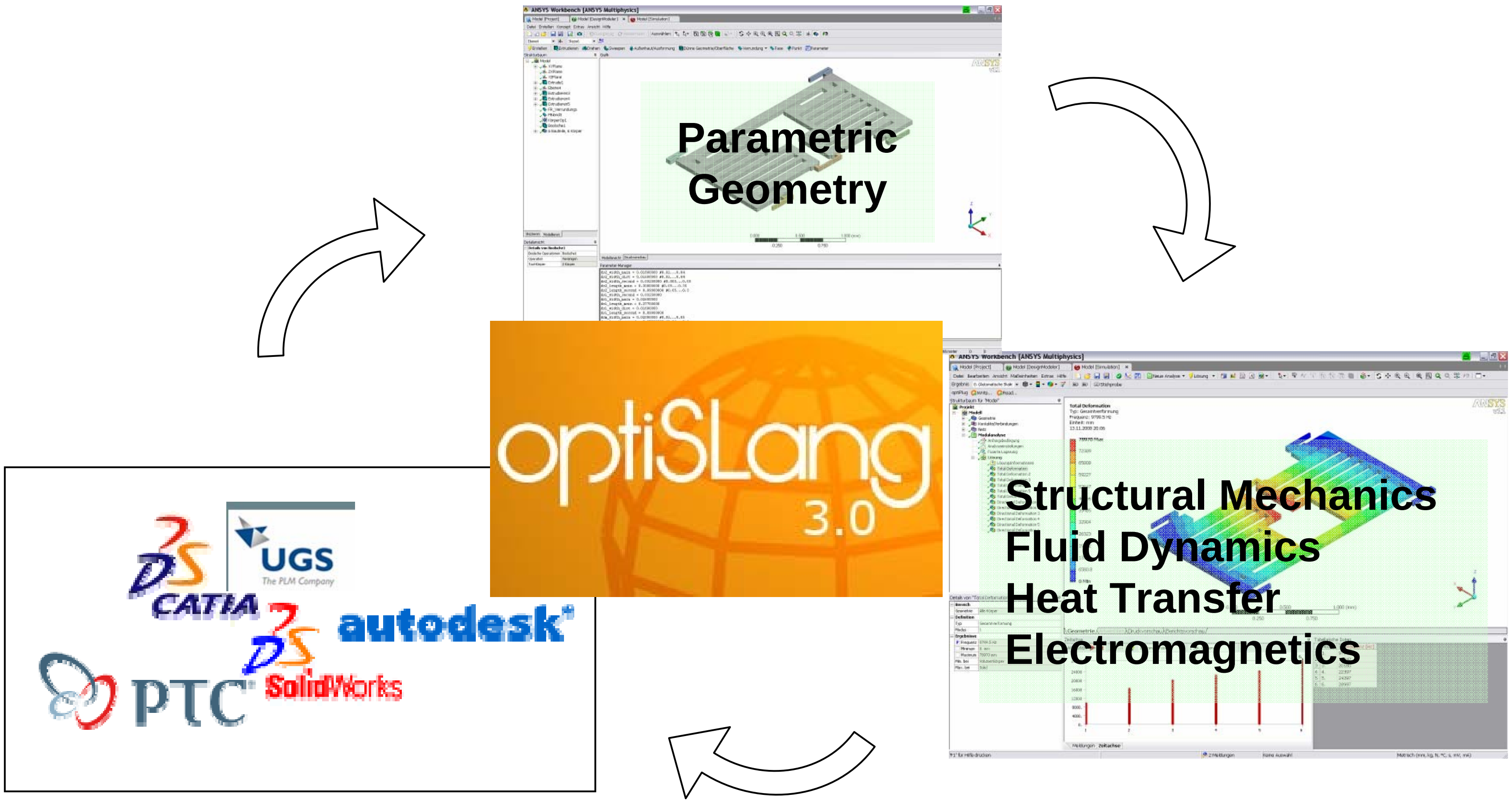
- **Angular Rate Sensor**
  - Purpose
    - Image stabilisation in digital cameras
    - Roll Over Detection in automotive industry
    - Sensors in game controlers
    - Signal for navigation systems where GPS signal is missing





Optimization of a sensor structure

- **Workbench integrated Workflow**



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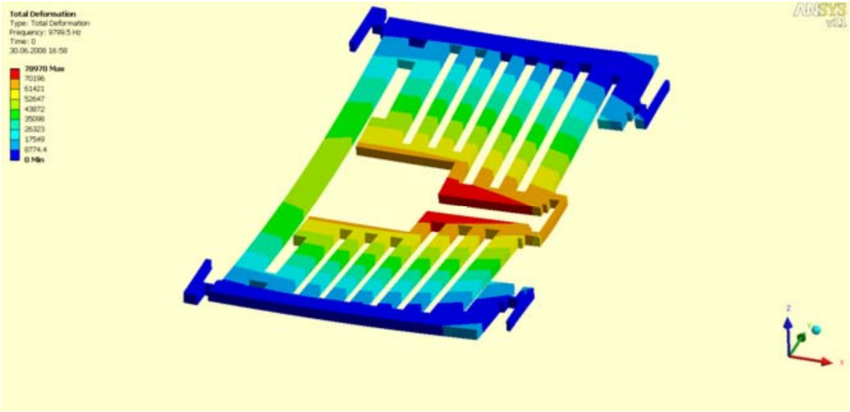
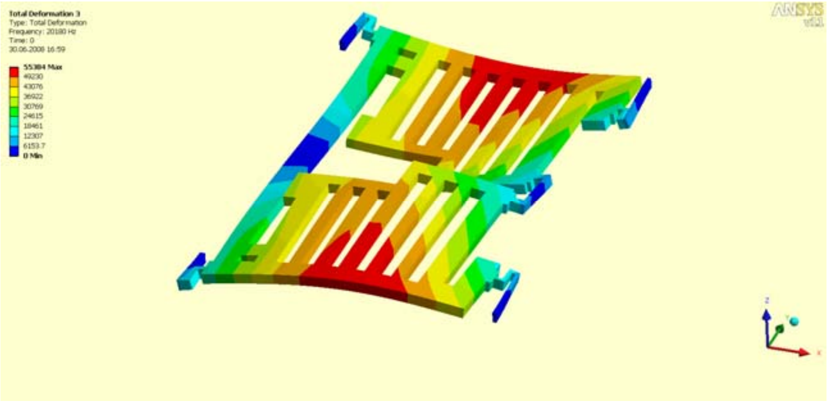
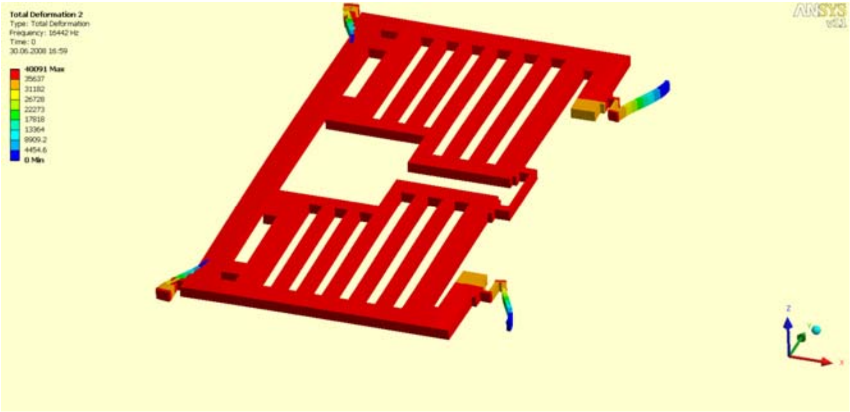
Optimization of a sensor structure

- **Requirements**
  - Not only Eigenfrequencies and oder of modes are important
  - Certain mode shapes must occur at certain Eigenfrequencies

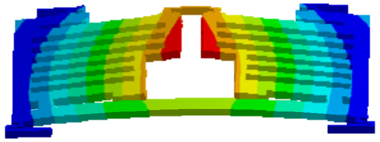






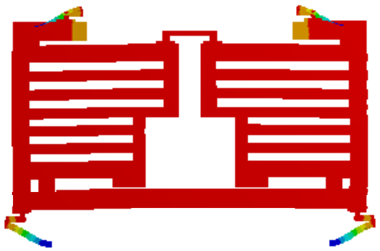
Optimization of a sensor structure

Start Design

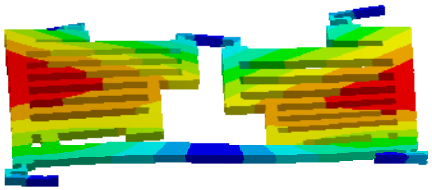


1. Symmetric out of plane

Mode	Frequency [Hz]
1.	9799.5
2.	16442
3.	20180
4.	22397
5.	24397
6.	28997

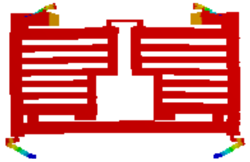


2. In Plane

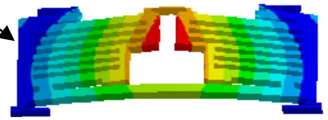


3. Asymmetric out of plane

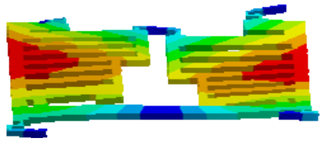
Goal Design



1. In Plane
7300 Hz



2. Symmetric out of plane
9000 Hz



3. Asymmetric out of plane
17000 Hz

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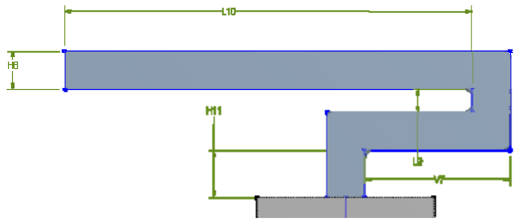
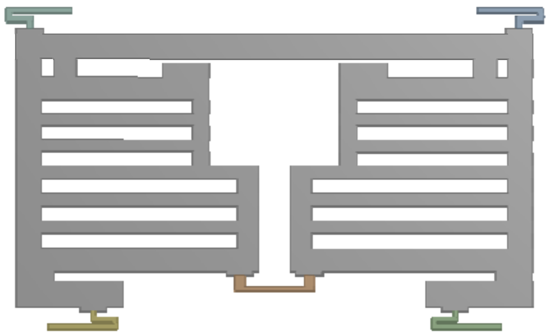
Optimization of a sensor structure

- **Parameters Input**

  13 CAD Parameters

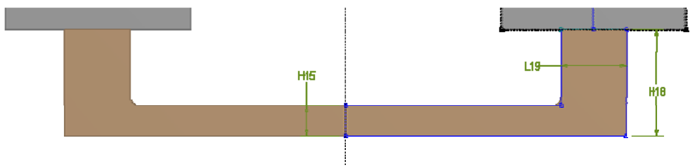


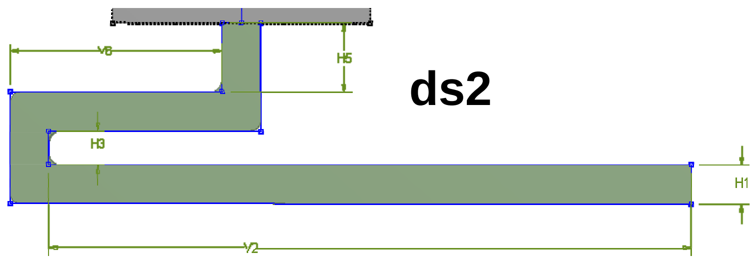
ds1



☑	CAD	P4	ds2_width_main	1.8e-002
☑	CAD	P5	ds2_width_dist	1.6e-002
☑	CAD	P6	ds2_width_second	3.25e-002
☑	CAD	P7	ds2_length_main	0.3
☑	CAD	P8	ds2_length_second	9.9e-002
☑	CAD	P9	ds1_width_second	3.25e-002
☑	CAD	P10	ds1_width_main	2.6e-002
☑	CAD	P11	ds1_length_main	0.277
☑	CAD	P12	ds1_width_dist	1.6e-002
☑	CAD	P13	ds1_length_second	9.9e-002
☑	CAD	P14	dsm_width_main	2.e-002
☑	CAD	P15	dsm_length_second	7.e-002
☑	CAD	P16	dsm_width_second	4.25e-002

dsm





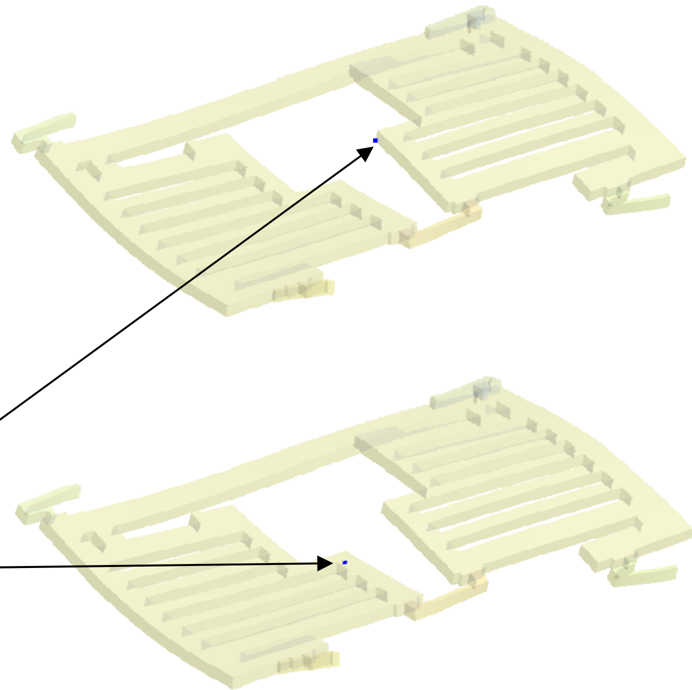
ds2

Optimization of a sensor structure

- **Parameters Output**
  - Frequencies
  - Out of plane displacements

For example 3rd mode:

Analysis	P1	freq1	9810.4 Hz
Analysis	P2	freq2	16447 Hz
Analysis	P3	freq3	20242 Hz
Analysis	P17	1uzA	79007 mm
Analysis	P18	1uzB	78880 mm
Analysis	P19	2uzA	-5.1765e-002 mm
Analysis	P20	2uzB	-0.24207 mm
Analysis	P21	3uzA	39094 mm
Analysis	P22	3uzB	-39163 mm



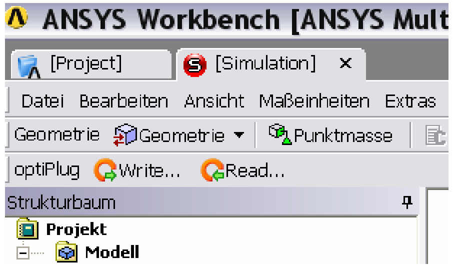
inplane mode: uz≈0
symmetric out of plane: uza ≈ uzb
asymmetric out of plane: uza ≈ -uzb

Optimization of a sensor structure

- **Strategy**
  - Global Latin Hypercube sampling to find out about sensitivities and to understand the model behavior
  - Use Genetic Algorithm to find islands of possible optima
  - Determine local sensitivities to pick out the most promising paramerters for subsequent optimization
  - Use Adaptive Response Surface optimization algorithm to improve the result
  - Do a Robustness Analysis to get the range of scatter

Optimization of a sensor structure

- **1. Set up**
  - Plug In for optiSlang in ANSYS Workbench
  - Set up boundaries for inputparameters, constraints and objective



Opti | Output | Constraints | Objectives | Strings

#	Name	Value	Ref.Value	Lower Bound	Upper Bound	Type	Format	Active	Const...
1	ds2_width_main	0.018	0.018	0.01	0.04	continuous	%20.14f	☑	☐
2	ds2_width_dist	0.016	0.016	0.01	0.04	continuous	%20.14f	☑	☐
3	ds2_width_second	0.0325	0.0325	0.0050	0.05	continuous	%20.14f	☑	☐
4	ds2_length_main	0.3	0.3	0.05	0.35	continuous	%20.14f	☑	☐
5	ds2_length_second	0.099	0.099	0.05	0.3	continuous	%20.14f	☑	☐
6	ds1_width_second	0.0325	0.0325	0.0050	0.05	continuous	%20.14f	☑	☐
7	ds1_width_main	0.026	0.026	0.01	0.04	continuous	%20.14f	☑	☐
8	ds1_length_main	0.277	0.277	0.05	0.35	continuous	%20.14f	☑	☐
9	ds1_width_dist	0.016	0.016	0.01	0.04	continuous	%20.14f	☑	☐
10	ds1_length_second	0.099	0.099	0.05	0.3	continuous	%20.14f	☑	☐
11	dsm_width_main	0.02	0.02	0.01	0.05	continuous	%20.14f	☑	☐
12	dsm_length_sec								
13	dsm_width_sec								

Opti | Output | Constraints | Objectives | Strings

#	Name	Type	Formula	Active
1	shape1A	inequality	50-fabs(A1uz)	☑
2	shape1B	inequality	50-fabs(B1uz)	☑
3	shape2A	inequality	fabs(A2uz)-5000	☑
4	shape2B	inequality	fabs(B2uz)-5000	☑
5				

Opti | Output | Constraints | Objectives | Strings

#	Name	Formula	Type	Active
1	freq1	fabs(freq1-7300)	term	☐
2	freq2	fabs(freq2-9000)	term	☐
3	freq3	fabs(freq3-17000)	term	☐
4	freqs	1.0*freq1+1.0*freq2+1.0*freq3	objective	☑

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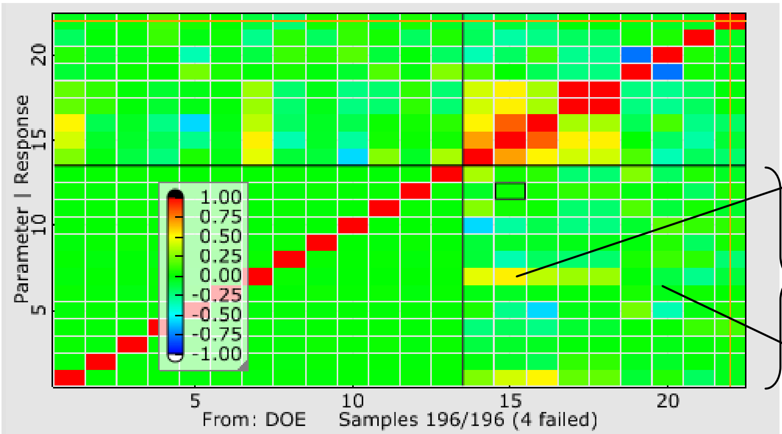
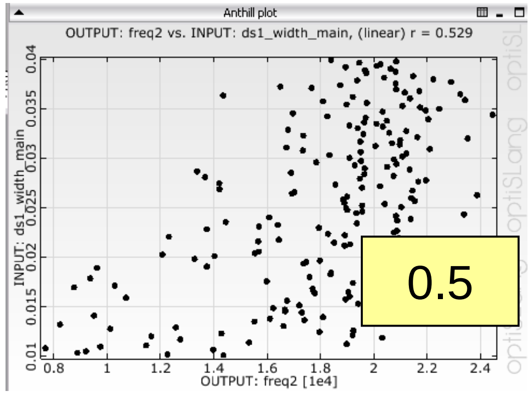
Optimization of a sensor structure

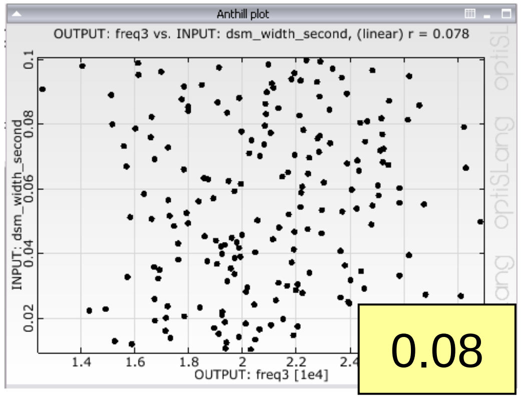
- **2. Latin Hypercube Sampling for Global sensitivities**
  - 200 random Samples appr. 1min each



Input parameters

Response parameters





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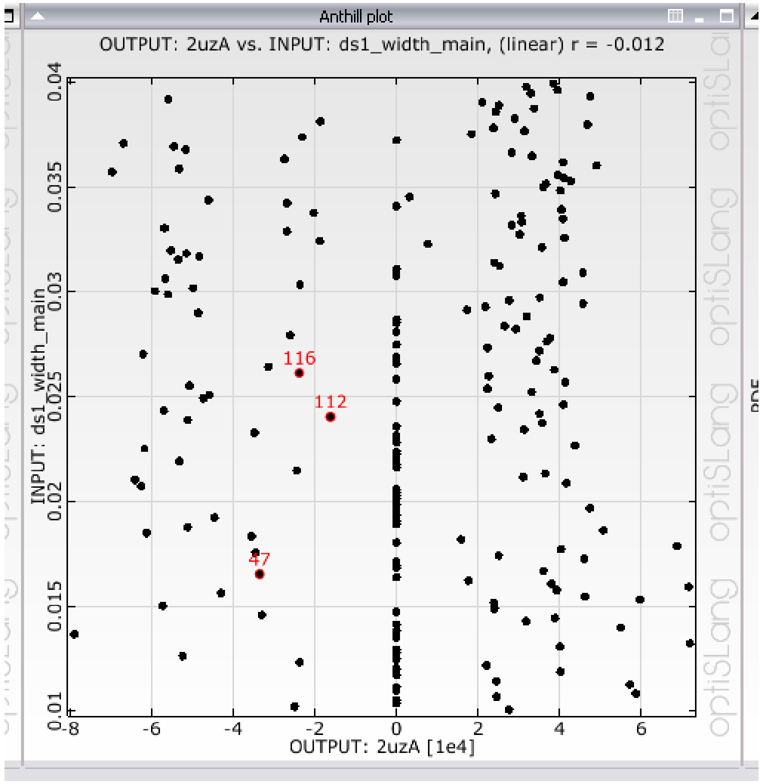
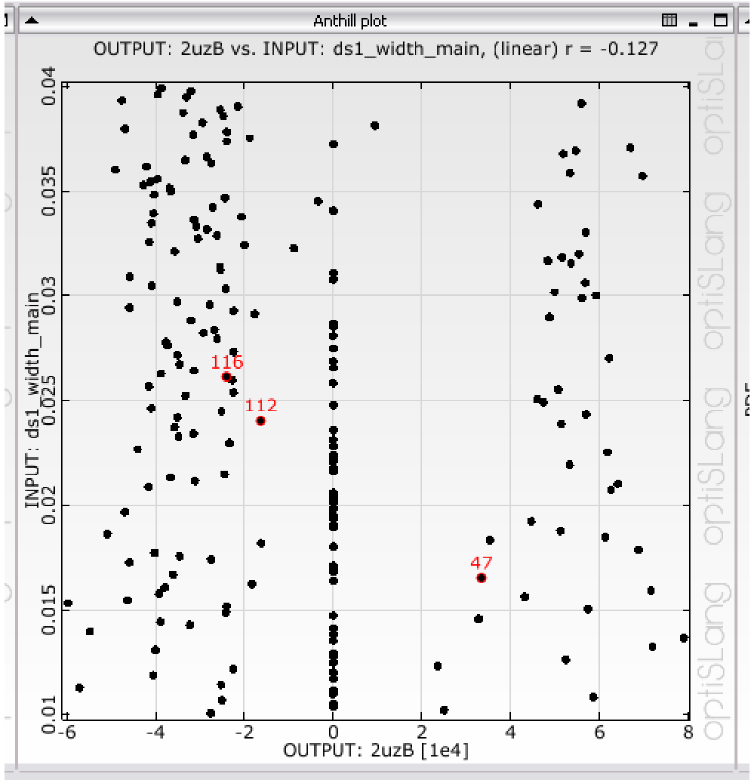
Optimization of a sensor structure

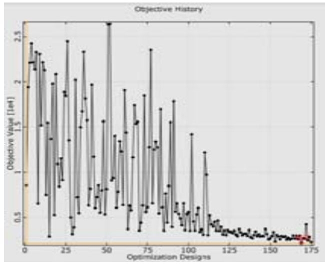
- **2. Global Sensitivities**
  - ‘Jumping Modes’ make manual optimization difficult

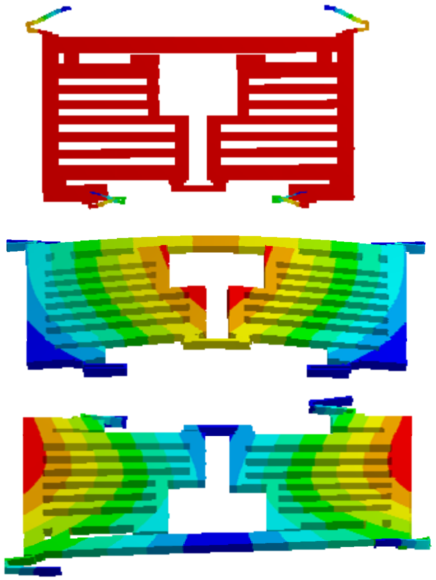




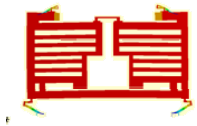
Optimization of a sensor structure

- **3. Genetic algorithm to find areas of possible optimum**
  - More stochastic approach, global search
  - Good for many parameters
  - Insusceptible to failed design points
  - 170 Samples, 3hours: Right order,
    first 2 Eigenfrequencies already close to goal



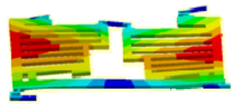


Mode	Frequency [Hz]
1.	7654.9
2.	9384.2
3.	15611
4.	17284
5.	24252
6.	24292



1. In Plane
7300 Hz

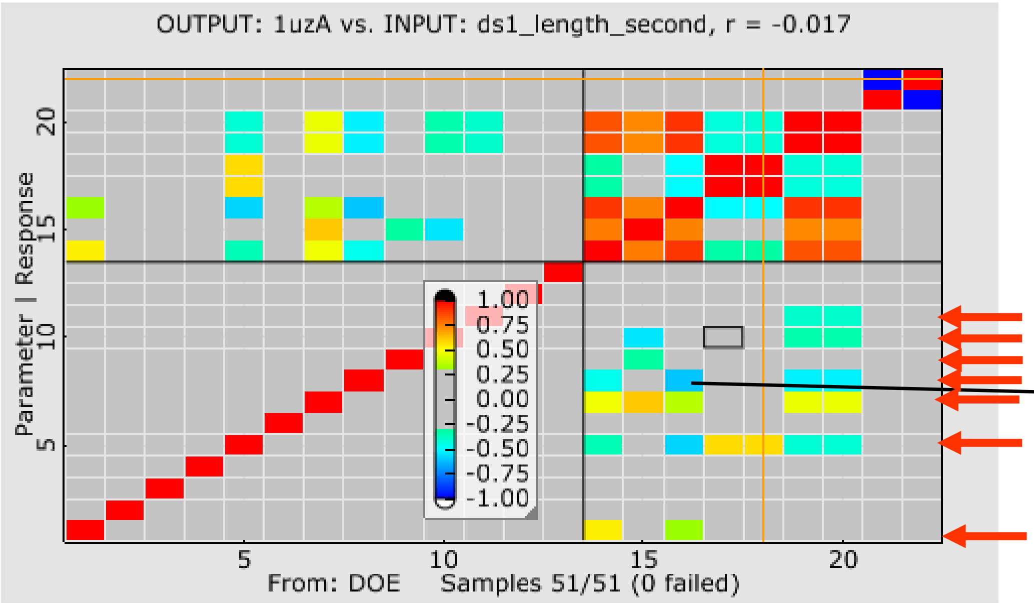
2. Symmetric out of plane
9000 Hz

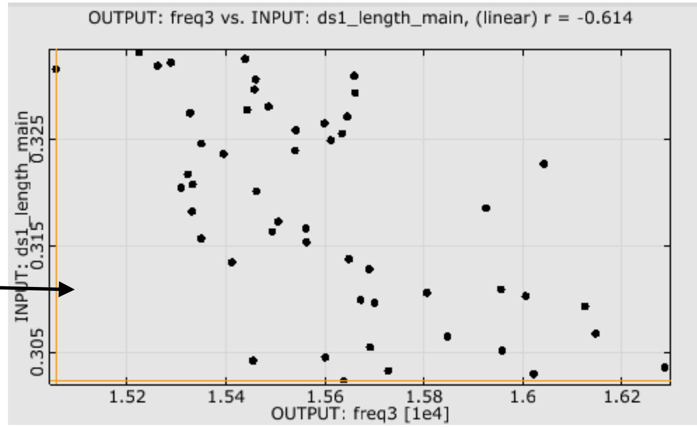


3. Asymmetric out of plane
17000 Hz

Optimization of a sensor structure

- **4. Local sensitivities**
  - Use best design from GA
  - Vary all parameters 5%
  - Only the 7 most sensitive inputparameters are used for subsequent optimization run





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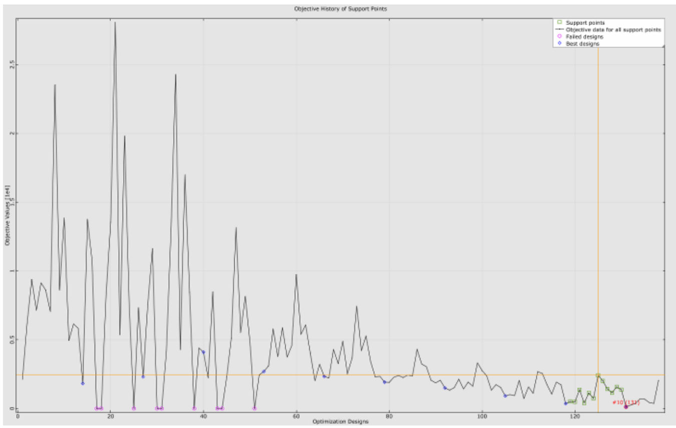
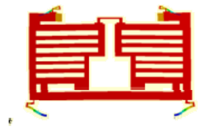
Optimization of a sensor structure

- **5. Use Adaptive Response Surface method**
  - Low order response surface is generated (Cost effective)
  - This surface is moved adaptively closer to the optimum
  - Very effective with less than 15 Parameters and good start value
  - Can handle failed designs
  - Computation time 2.5 hours



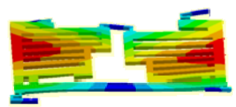
Tabular Data

	Mode	Frequency [Hz]
1	1.	7288.9
2	2.	9021.3
3	3.	17085
4	4.	20264
5	5.	20840
6	6.	24150



1. In Plane
7300 Hz

2. Symmetric out of plane
9000 Hz



3. Asymmetric out of plane
17000 Hz

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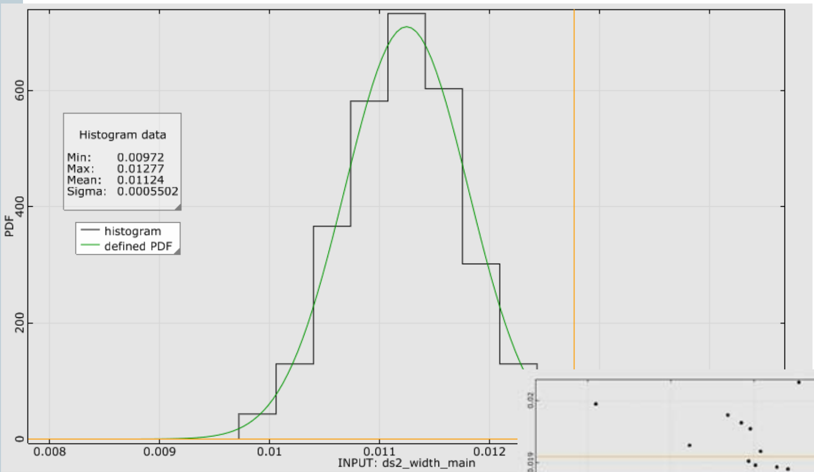
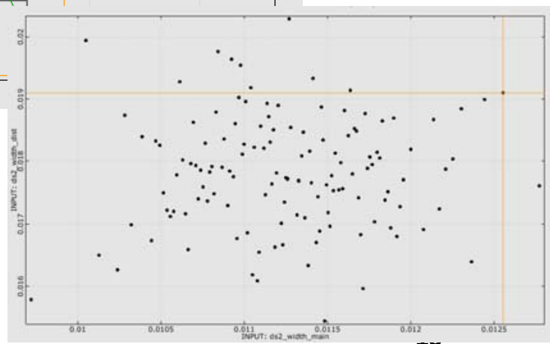
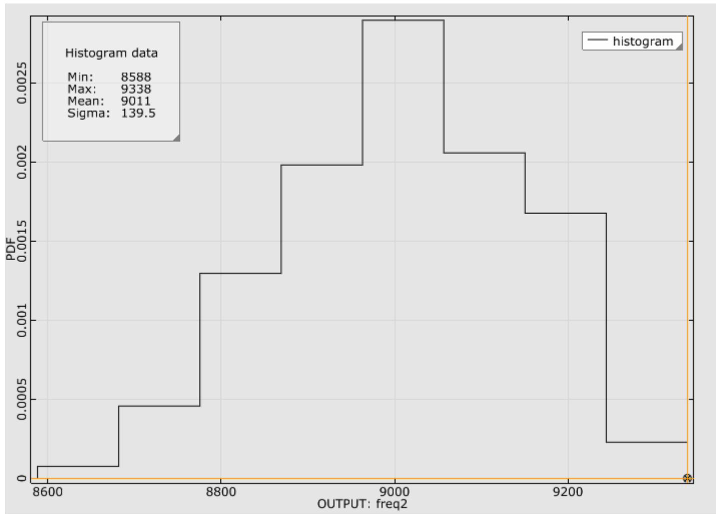
Optimization of a sensor structure

- **6. Robustness Analysis**
  - Uncertainty of input variables leads to uncertainty of results
  - Latin Hyper Cube Sampling 150 Samples
  - Computation time < 3hours

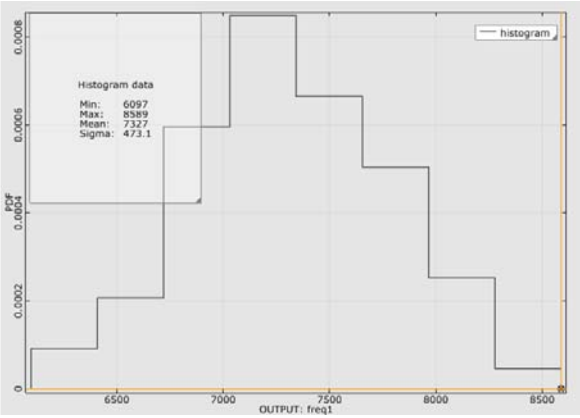




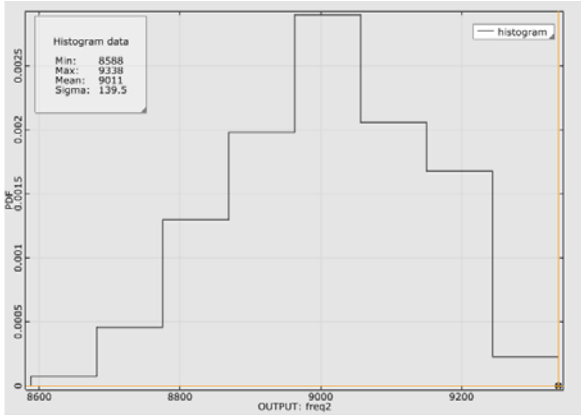


Optimization of a sensor structure

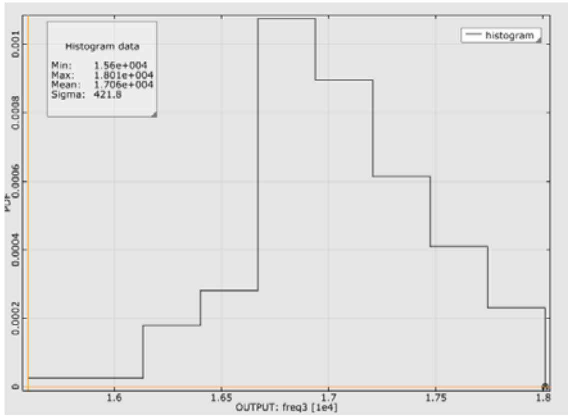
- **6. Robustness Analysis**
  - What scatter is to be expected?



Most within ± 700 Hz



Most within ± 200 Hz



Most within ± 500 Hz
and skew

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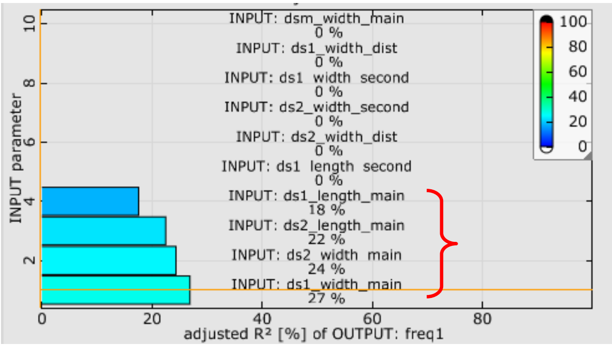
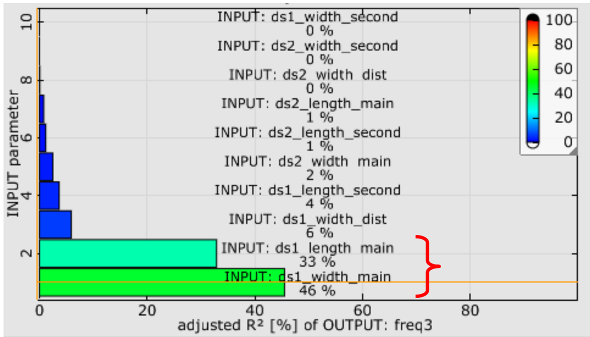
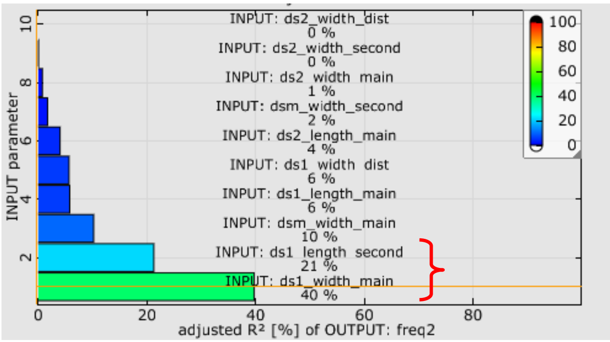
Optimization of a sensor structure

- **6. Robustness Analysis**
  - How can production be improved to get robust results?
  - Find input parameters which contribute most variation to the result, Coefficient of determination







ds1_length_main
ds1_width_main
ds1_length_second
ds2_length_main
ds2_width_main

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Optimization of a sensor structure

- **Results**
  - Time effort (hours):

	Preparation	Computation
Model Set up (DM, DS)	2	-
Genetic algorithm	0.25	3
Local sensitivities	0.25	1
Adaptive Response Surface	0.15	2.5
Robustness Analysis	0.25	3
	3.4	**9.5**

Less than 1.5 days with minimum user interaction

Optimization of a sensor structure

- **Results**
  - What you get:
    - Integrated workflow
    - Easy and robust approach for optimization problems with ‘jumping’ results
    - Applicable for arbitrary number of parameters
    - Handling of failed designs
    - Deep understanding for the system response
    - Proof of Robustness for production process