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Ansys WÜRTH ELEKTRONIK

Optimization of Inductive Magnetics on Silicon Devices with optiSLang

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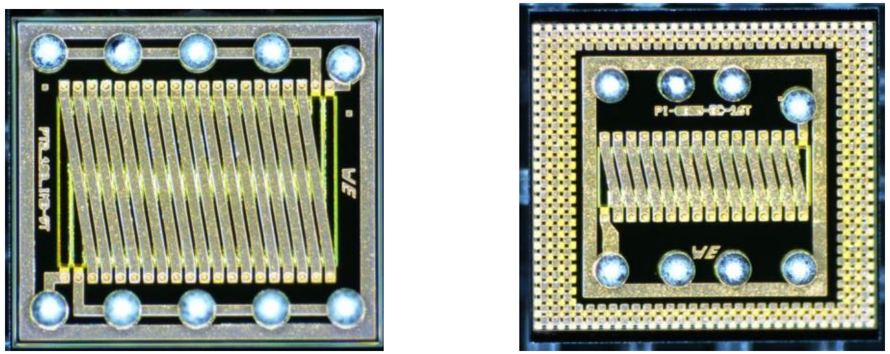
Overview

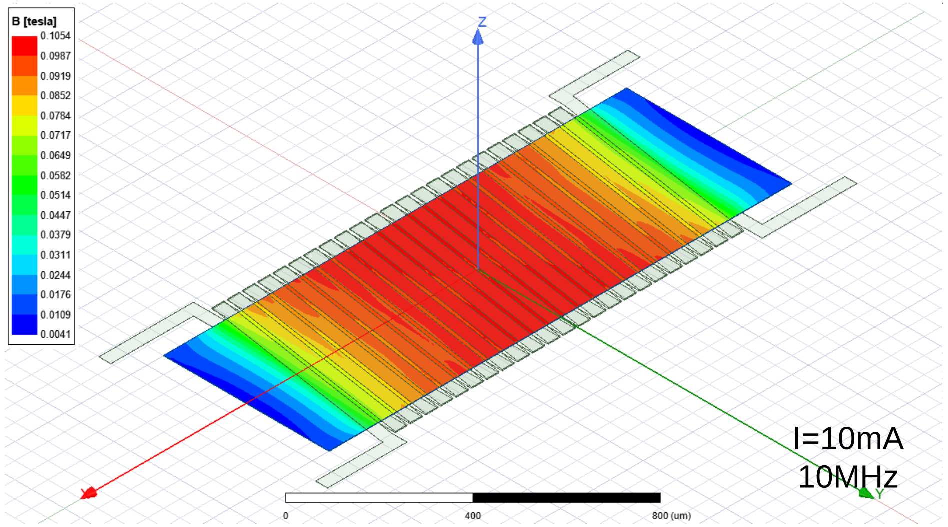
- **Introduction**
- **Design optimization**
- **Optimization with OptiSLang**
- **Results**
- **Conclusion**

Introduction

- **FEM (Finite-Element-Method) simulation is very important tool for development of magnetic microdevices or MEMS systems (Micro-Electro-Mechanical Systems) on silicon**
- **Ansys Maxwell is widely used software tool**
- **Ansys Maxwell allows estimation of device electrical parameters in static, time (frequency)-depending or transient domains**
- **Good match between simulation and real measurement**



Microtransformer and microinductor (2.6mm x 2.4mm)



Magnetic flux density in the core

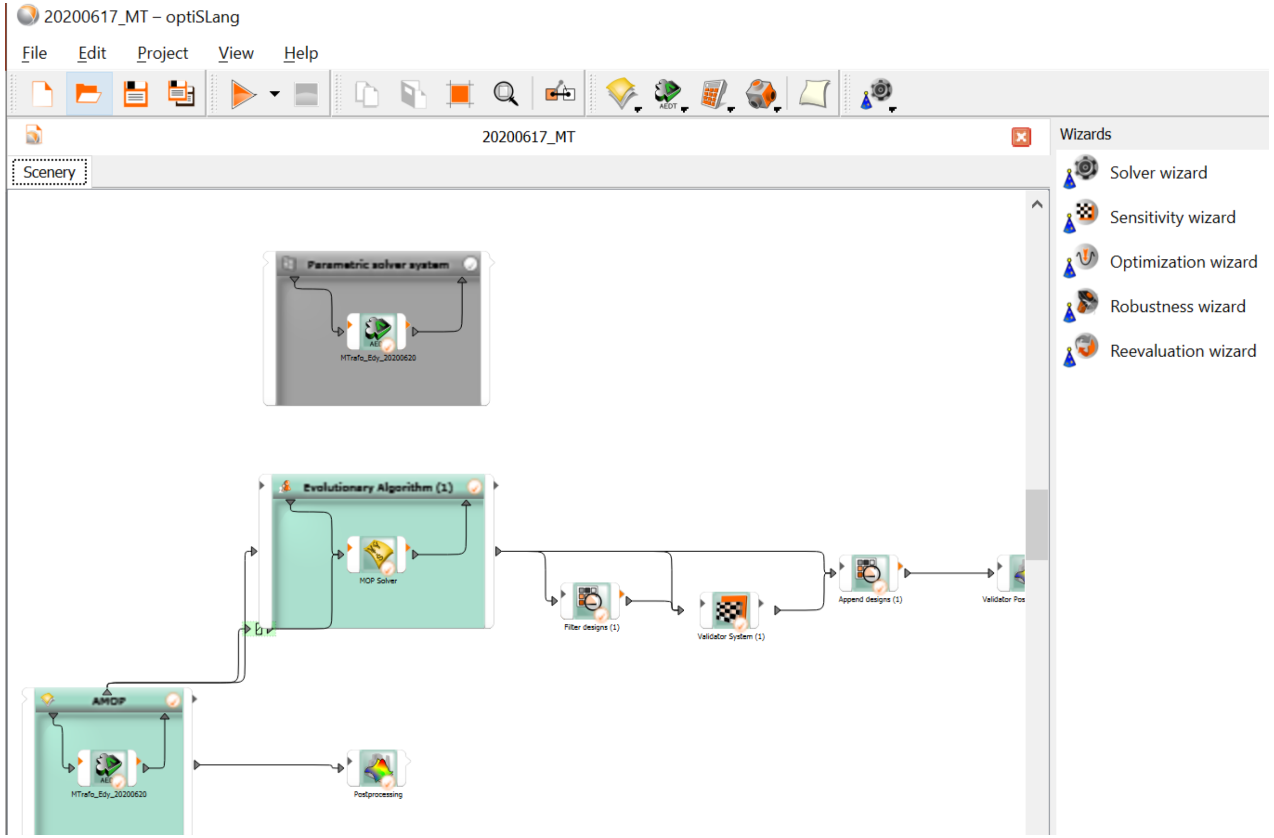
Design Optimization

- **Design steps for development of inductors & transformers**
  - First analytical calculation
  - Definition of important design parameters and requirements (part size, number of turns, inductance….)
  - Creating of parameterized model in Ansys Maxwell
  - Simulation of the initial model
  - Parameters variation using Optimetrics (20-30 models) ➔➔➔ **finding of optimal design**

- **After 20 – 30 simulations (models) an optimal design with desired L values can be achieved**
- **Other design parameters (i.e. Rdc, coupling factor, Q) are often not optimal**
- **Another problem is that the parameter changes are often parallel, i.e. if we increase the number of turns, the inductance increases as well as the resistance. For such cases, a Pareto optimization can help (i.e. OptiSLang tool)**

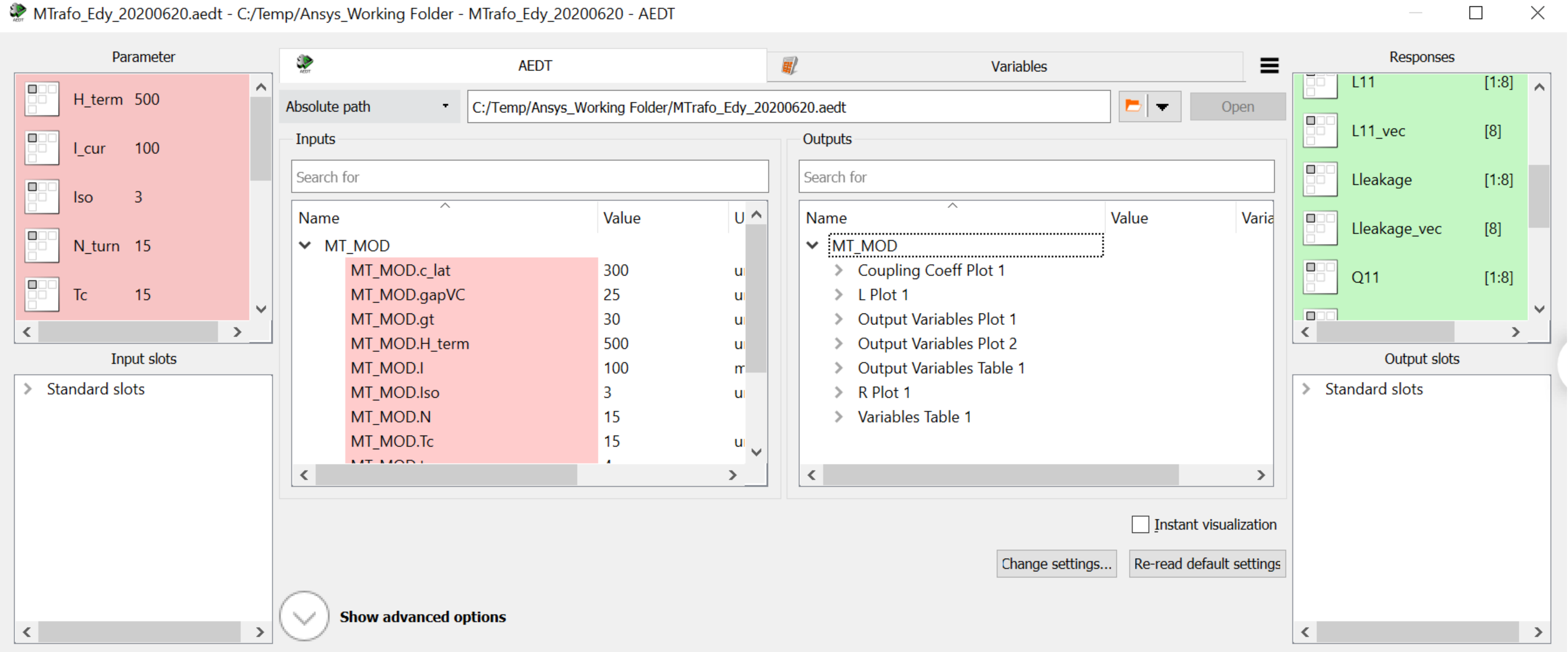
Optimization with OptiSLang I

- OptiSlang allows finding out of an optimal design based on more criteria from huge number of simulations (designs)
- The initial simulation from Ansys Maxwell is input for OptiSlang
- All parameters are defined as value range
- Target design parameter are defined as responses
- Optimization is based on criteria: objectives, constraints, limits



OptiSLang software environment

Optimization with OptiSLang II



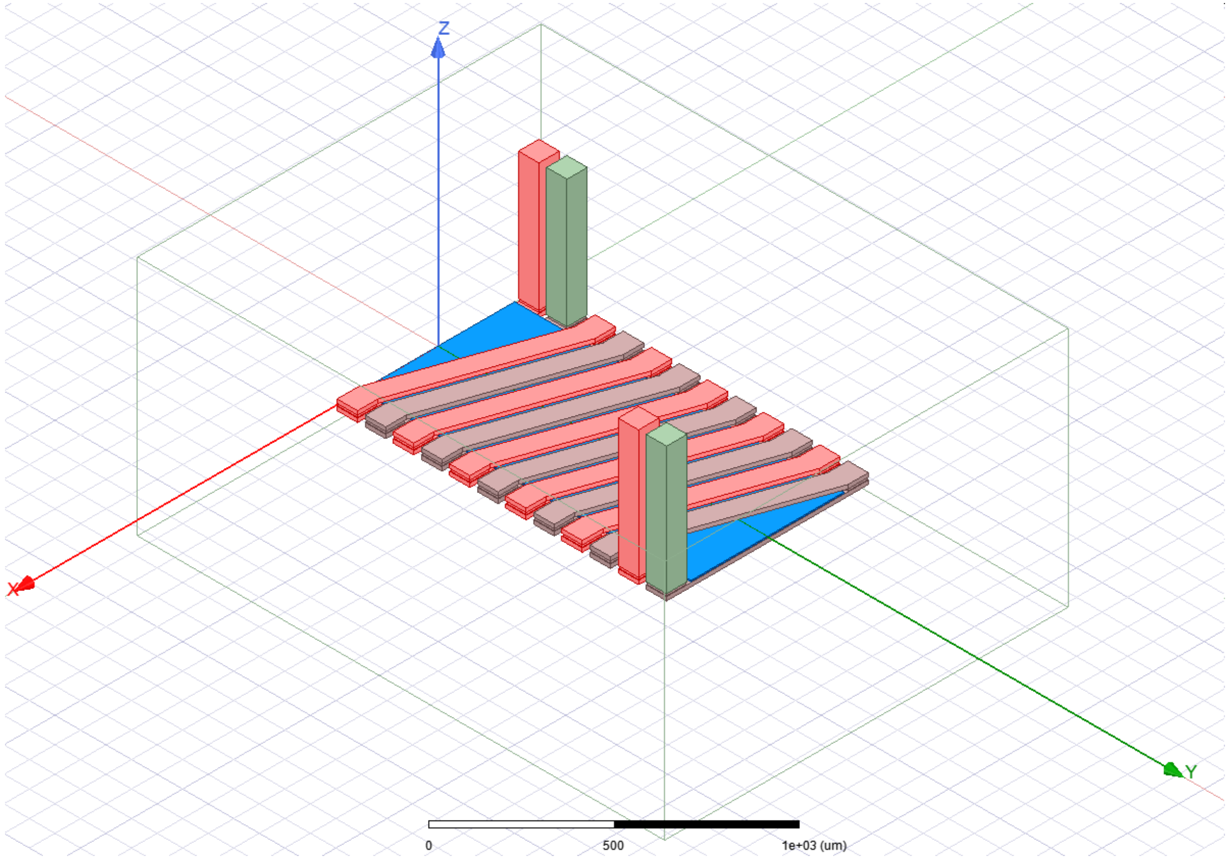
Definition of parameters and responses of AEDT Model in OptiSlang

Optimization with OptiSLang III – Aim

- **AEDT Model with Ansys Maxwell was created and simulated**
  - L value ~ 70nH
  - K ~ 0.85

- **Aim is to increase inductance L, coupling factor K, and to reduce resistance R**

- **The aim was to find out an optimal design of microtransformer with this properties:**
  - Inductance L ~ (80nH – 100nH)
  - Minimum R value
  - Coupling factor K > 0.86 (if possible >0.9)



AEDT Model of the microtransformer

Optimization with optiSLang IV – Run1

- **First optimization run**
- **Parameter and parameter range are defined**
  - 12 geometrical parameters – 6 dependent
  - **6 independent input parameters used for simulation**
- **Goals and constraints are set up:**
  - Goals:
    - L11, L22 maximized
    - R11, R22 minimized
  - Constraint:
    - Coupling factor > 0.86

Criteria

Name	Type	Expression	Criterion	Limit	
obj_max_L11_w20_50	Objective	max_L11_w20_50	MAX		-121.623
obj_max_L22_w20_50	Objective	max_L22_w20_50	MAX		-121.72
obj_min_R11_w20_50	Objective	min_R11_w20_50	MIN		1.19918
obj_min_R22_w20_50	Objective	min_R22_w20_50	MIN		1.1969
constr_CplCoef_12_const	Constraint	CplCoef_12_const	≥	0.86	0.85398 ≥ 0.86

Criteria for 1st AMOP (adaptive Metamodel of Optimal Prognosis (*MOP*))

Parametric solver system - Parametric System

Parameter | Criteria | Other | Result designs

	Name	Parameter type	Reference value	Constant	Operation	Value type	Resolution	Range	Range plot
1	c_lat	Optimization	300	☐		REAL	Continuo...	2... 4...	
2	gap...	Optimization	25	☐		REAL	Continuo...	15 30	
3	gt	Optimization	30	☐		REAL	Continuo...	20 35	
4	N_t...	Optimization	15	☐		REAL	Discrete by value	2; 3; ...	
5	Via	Dependent	50	☐	Wc-30				
6	Wc	Optimization	80	☐		REAL	Continuo...	60 1...	
7	wm	Optimization	800	☐		REAL	Continuo...	2... 2...	
8	Iso	Optimization	3	☑		REAL	Continuo...	2.7 3.3	
9	Tc	Optimization	15	☑		REAL	Continuo...	1... 1...	
10	tm	Optimization	4	☑		REAL	Continuo...	3.6 4.4	
11	I_cur	Optimization	100	☑		REAL	Continuo...	90 1...	
12	H_te...	Optimization	500	☑		REAL	Continuo...	4... 5...	

Parameter merging: Prefer defined

Show additional options

Input parameters of the microtransformer

Optimization with optiSLang V – Run1

- **Overview of parameters**
- **Some parameters are defined by technological design rules (i.e. Tc, Iso, tm)**

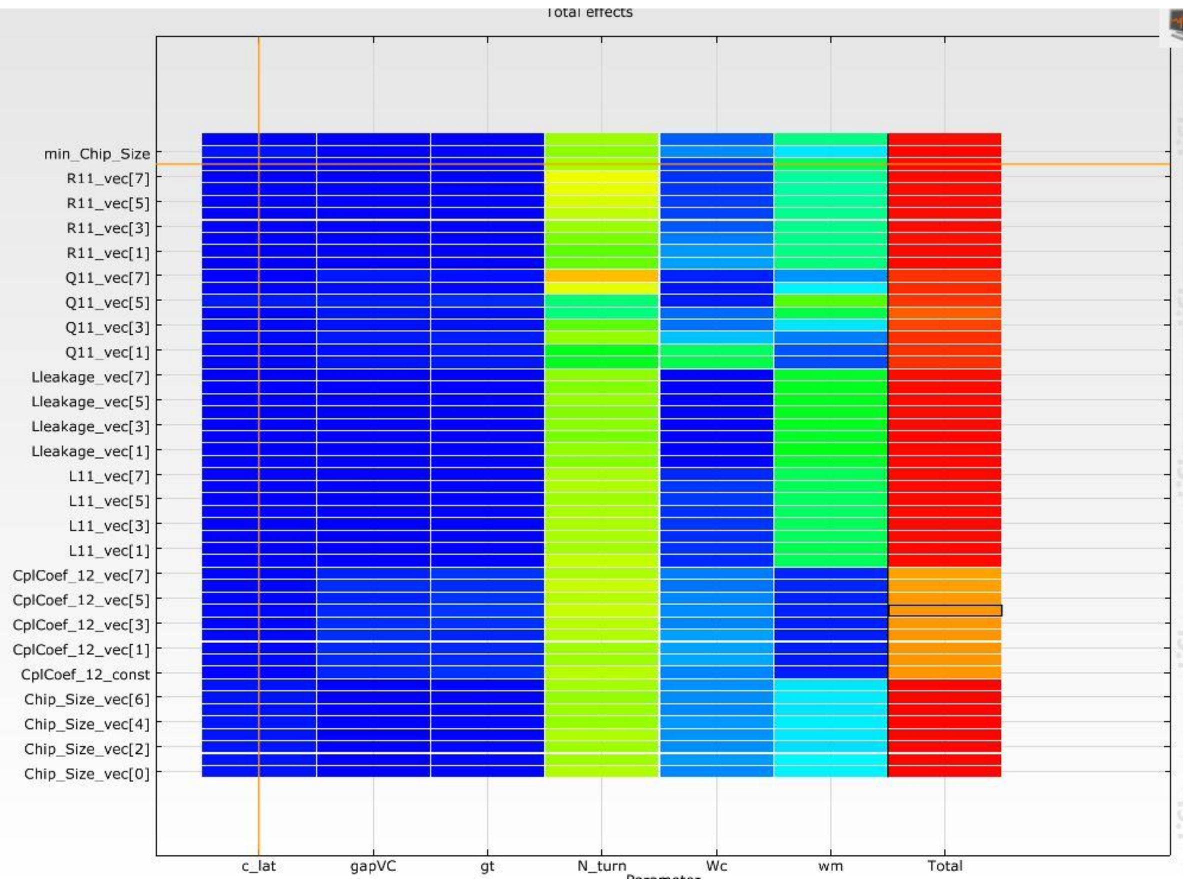
	Independent Parameters
wm	Width of magnetic core
Wc	Width of turns
gapVC	Distance between via and core (x-direction)
gt	Distance betwen two neighbour turns
c_lat	lateral length about active part
N	Number of turns

	Dependent Parameters / Constants
Tc (cons.)	Thickness of turns
Iso (cons.)	Thickness of insulation layer
Via = Wc - 30	Via size
tm (cons.)	Thickness of magnetic core
G = Wc + 2*gt	Distance between primary and secondary turns
P = G + Wc	Pitch of coil

Optimization with optiSLang VI –Run1

- **100 real solver runs with AMOP (Adaptive Metamodel of Optimal Prognosis)**
- **CoP Matrix (Coefficient of Prognosis) shows that only 3 of 6 inputs are important for all the responses → we can increase system understanding:**
  - most important drivers
  - less important drivers
  - nearly unimportant drivers
  - completely unimportant drivers
- **The explainability of all responses are really good**

Responses

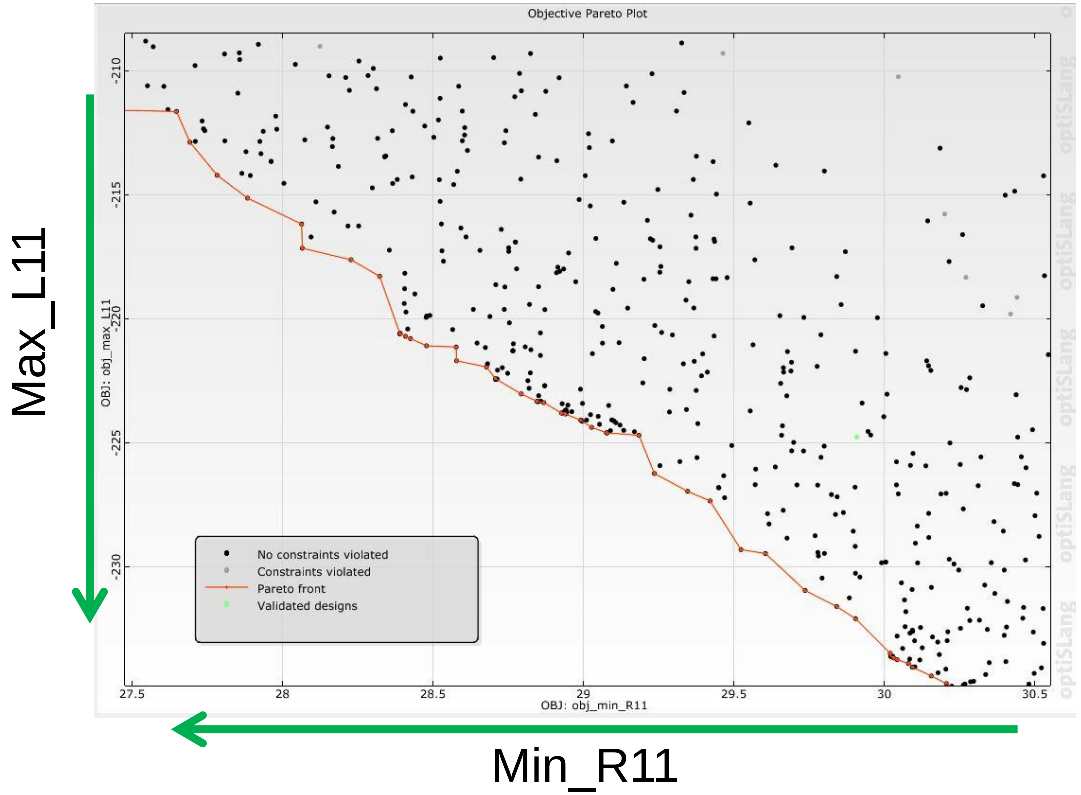


Inputs

CoP Matrix with important input parameters

Optimization with optiSLang VII – Run1

- **With this good explainability we can go on with Optimization on MOP without a real solver run with 10.000 designs and more**
- **Before we can minimize the 4 goals to 2 goals**
  - L11 & L22 have same behaviour
  - same for R11 & R22
- **Using evolutionary algorithm for this 2D Pareto optimization to get a good resolution of Pareto Front for decision making**



2D Pareto goals

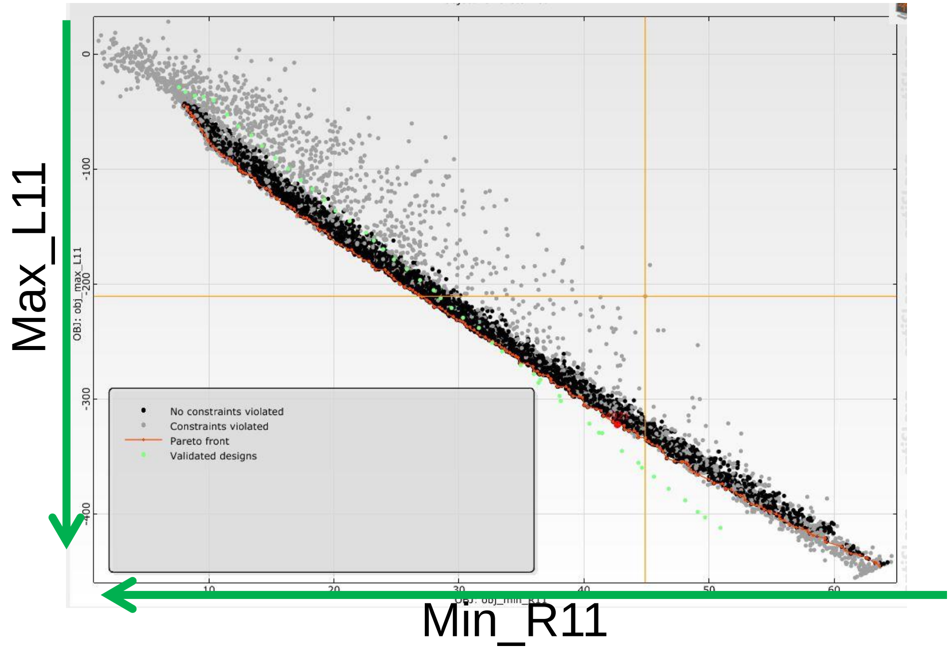
Optimization with optiSLang – Run2

- **To implement cost depended responses we start a new AMOP (real) + optimization (MOP)**
- **Criteria (goals & constraints) are updated**
  - Goals:
    - Only L11 maximized (L11 = L22)
    - Only R11 minimized (R11 = R22)
    - Chip Size as cost function minimized
  - Constraints:
    - Coupling factor > 0.88
- **Now a 3D Pareto Front are created**
- **Important parameter are defined and range of these parameter are tightly defined and updated in the third AMOP**

Criteria

Name	Type	Expression	Criterion	Limit	Evaluated expression
obj_min_R11	Objective	min_R11	MIN		0.746029
obj_max_L11	Objective	max_L11	MAX		-71.4477
obj_min_Chip_Size	Objective	min_Chip_Size	MIN		6.2307e-06
constr_CplCoef_12_const	Constraint	CplCoef_12_const	≥	0.88	0.855056 ≥ 0.88
new					

Criteria for 2nd AMOP



2D Pareto front of goals

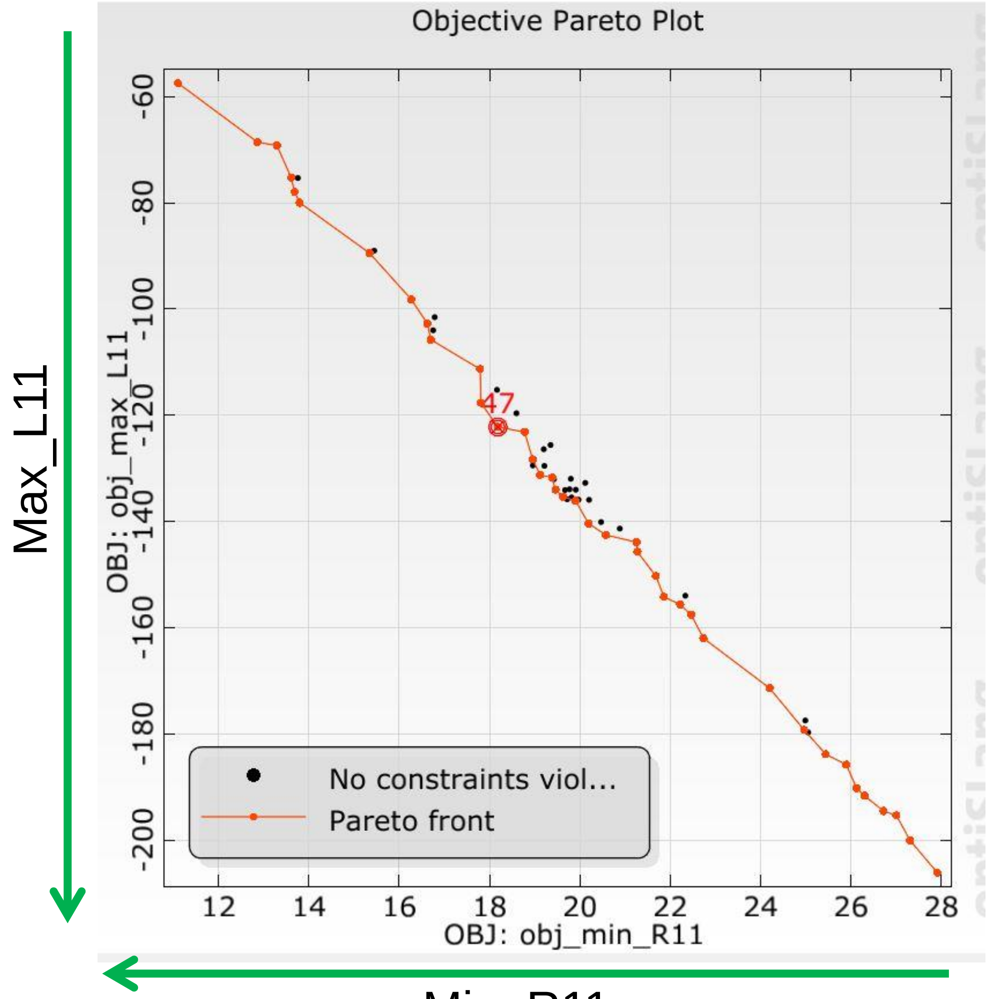
Optimization with optiSLang – Run3

- **In the third AMOP the criteria are combined**
- **Criteria (goals & constraints) are updated**
  - Goals:
    - Only L11 maximized (L11 = L22)
    - Only R11 (R11 = R22) + Chip size minimized
  - Constraints:
    - Coupling factor > 0.90
- **Range of some parameter are tight defined**

Criteria

Name	Type	Expression	Criterion	Limit	
obj_min_R11	Objective	min_R11*10+var_min_Chip_Size	MIN		13.691
obj_max_L11	Objective	max_L11	MAX		-71.4477
constr_CplCoef_12_const	Constraint	CplCoef_12_const	≥	0.9	0.855056 ≥ 0.9
var_min_Chip_Size	Variable	min_Chip_Size*1e6			6.2307

Criteria for 3rd AMOP

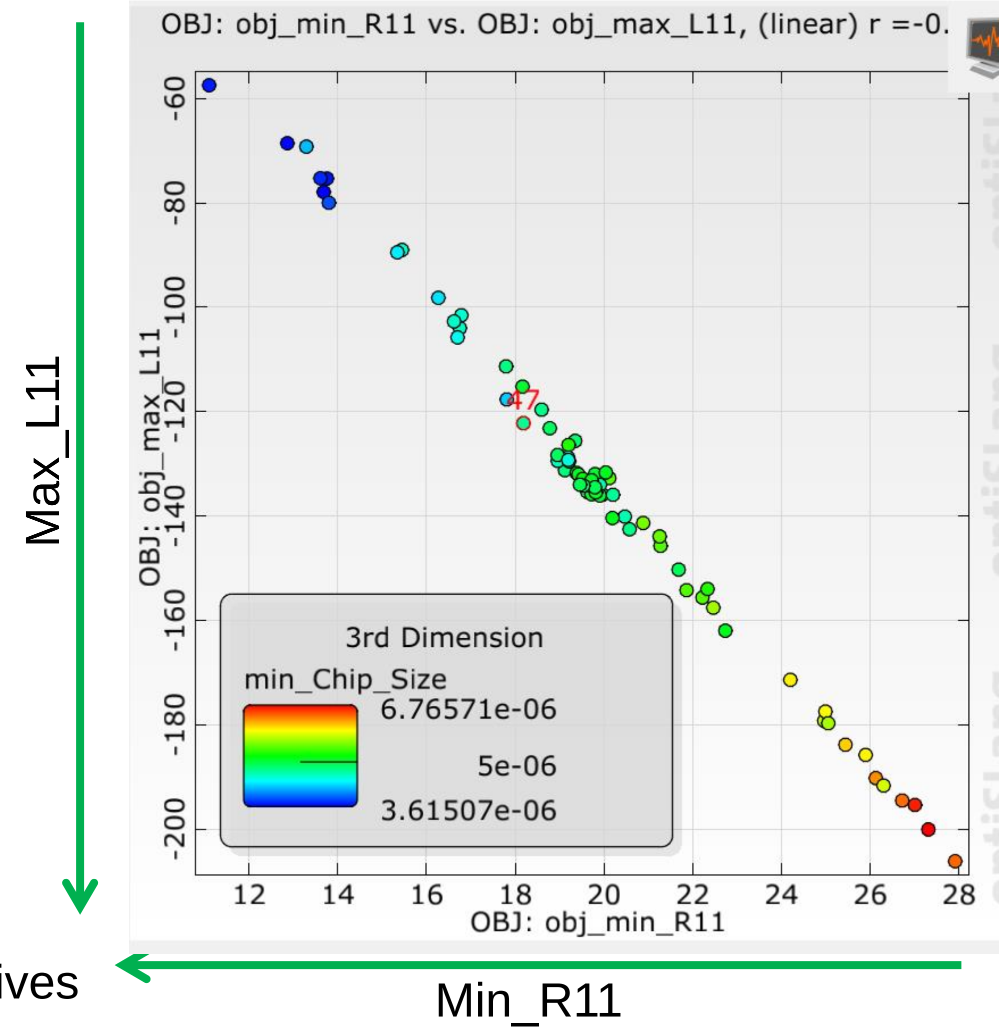


Min_R11

Pareto diagram

Optimization with optiSLang – Run3

- **We focused now an inductance range between 100nH and 150nH**
- **We chose design 47 as an optimal**
- **Design 47 has inductance of 122nH and coupling factor K>0.9**



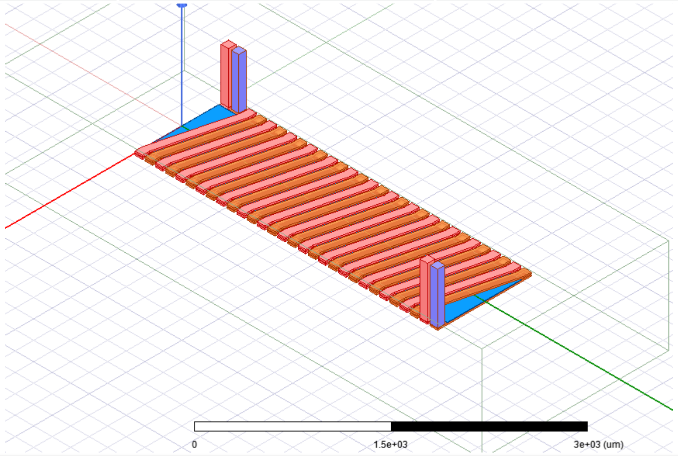
Anthill diagram:
Chip size over objectives

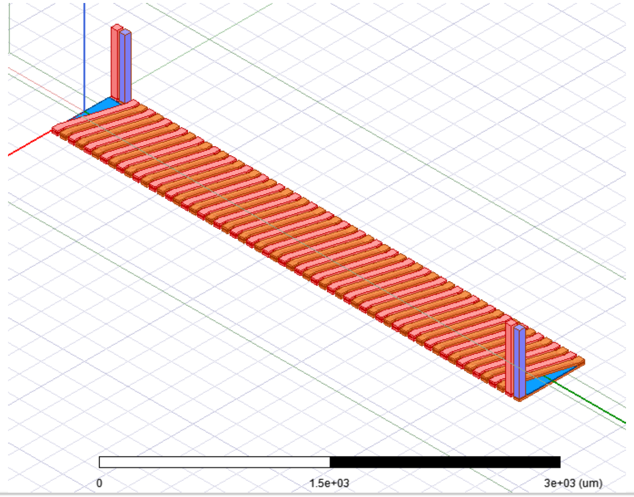
Results I – Designs Comparison

- **Comparison initial design vs. now best design**

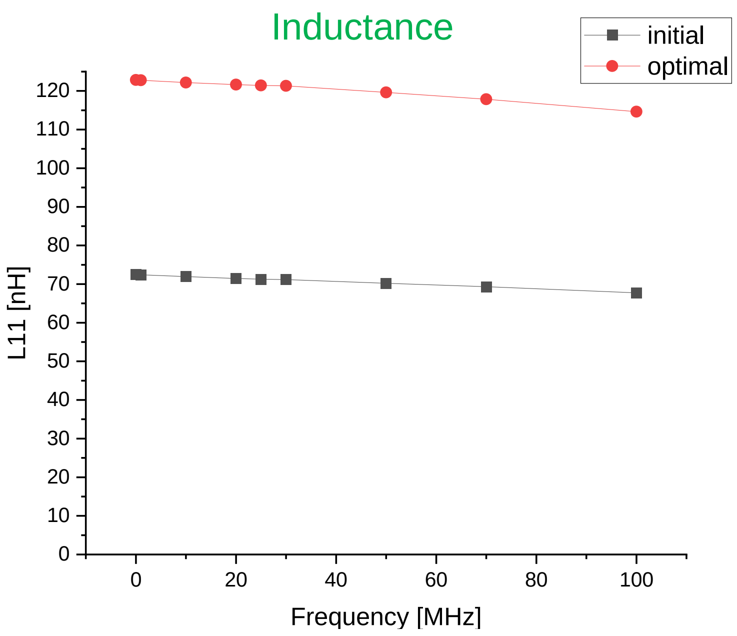
Param.	Initial Design	Best design
wm	800µm	450.2µm
Wc	80µm	54.6µm
gapVC	25µm	20.65µm
gt	30µm	20.06µm
c_lat	300µm	200µm
N	15	29

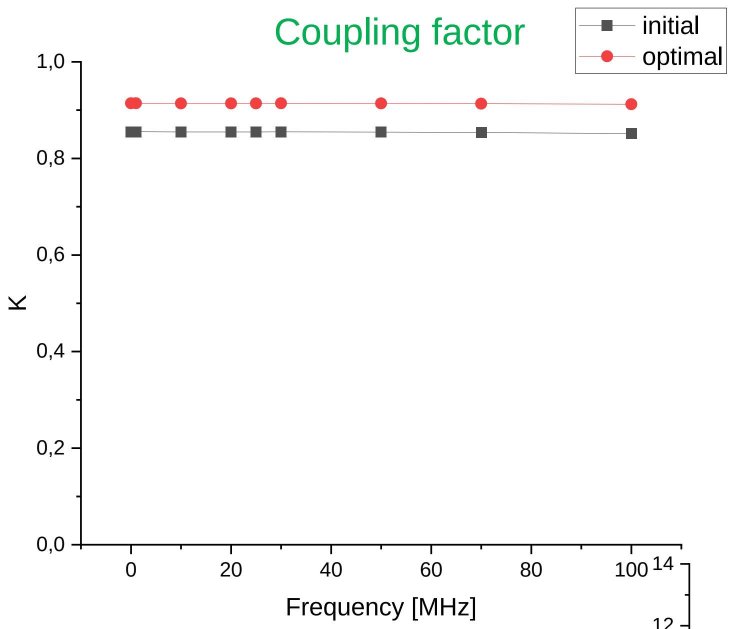
Responses	Initial Design (at 25MHz)	Best design (at 25MHz)
L11	71.5nH	120nH
R11	0.95Ω	1.57Ω
Q11	11.9	12.1
CoupCoef	0.855	0.914
Chip Size	6.23e-6m²	4.7e-6m²

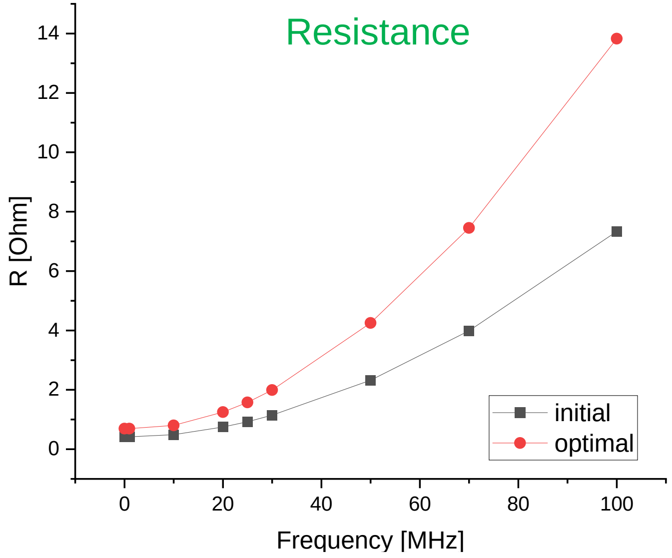


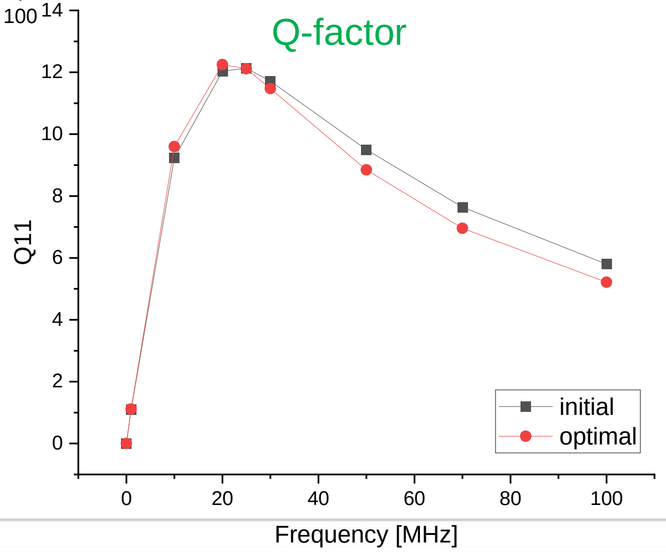


Results II – Designs Comparison









- **Comparison initial design vs. now best design**

Summary & Outlook

- **Implementation of OptiSlang&Maxwell for design optimization of microtransformer devices on silicon for high frequency applications is successful**
- **Development and fabrication of microinductor and microtransformer products based on OptiSLang simulation results**
- **Tolerance analysis should be in the next steps implemented → check optimal design with influence of input scattering**
- **HFSS simulation with OptiSlang for microtransformer and microinductor**