Optimization Analysis of the Integrated Micro-coil Geometry Parameters Influence on the Uniformity of the Magnetic Field Distribution

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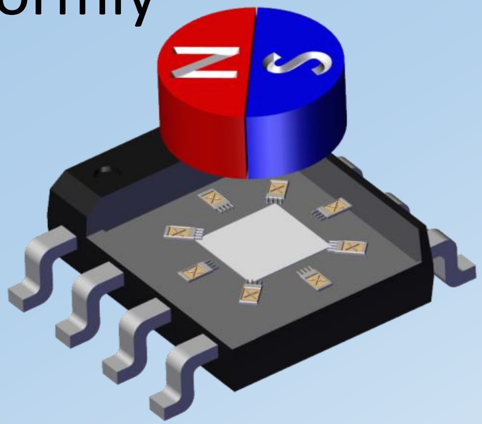
Miha Gradišek

- Researcher at Faculty of Electrical Engineering, University of Ljubljana, Slovenia
- Development of the SoC and ASIC designs in 180nm technology (Virtuoso Cadence & SEN)
- MEMS (incorporating Hall sensors)
- COMSOL Multiphysics simulations of magnetic systems
- 3D modeling (SolidWorks)

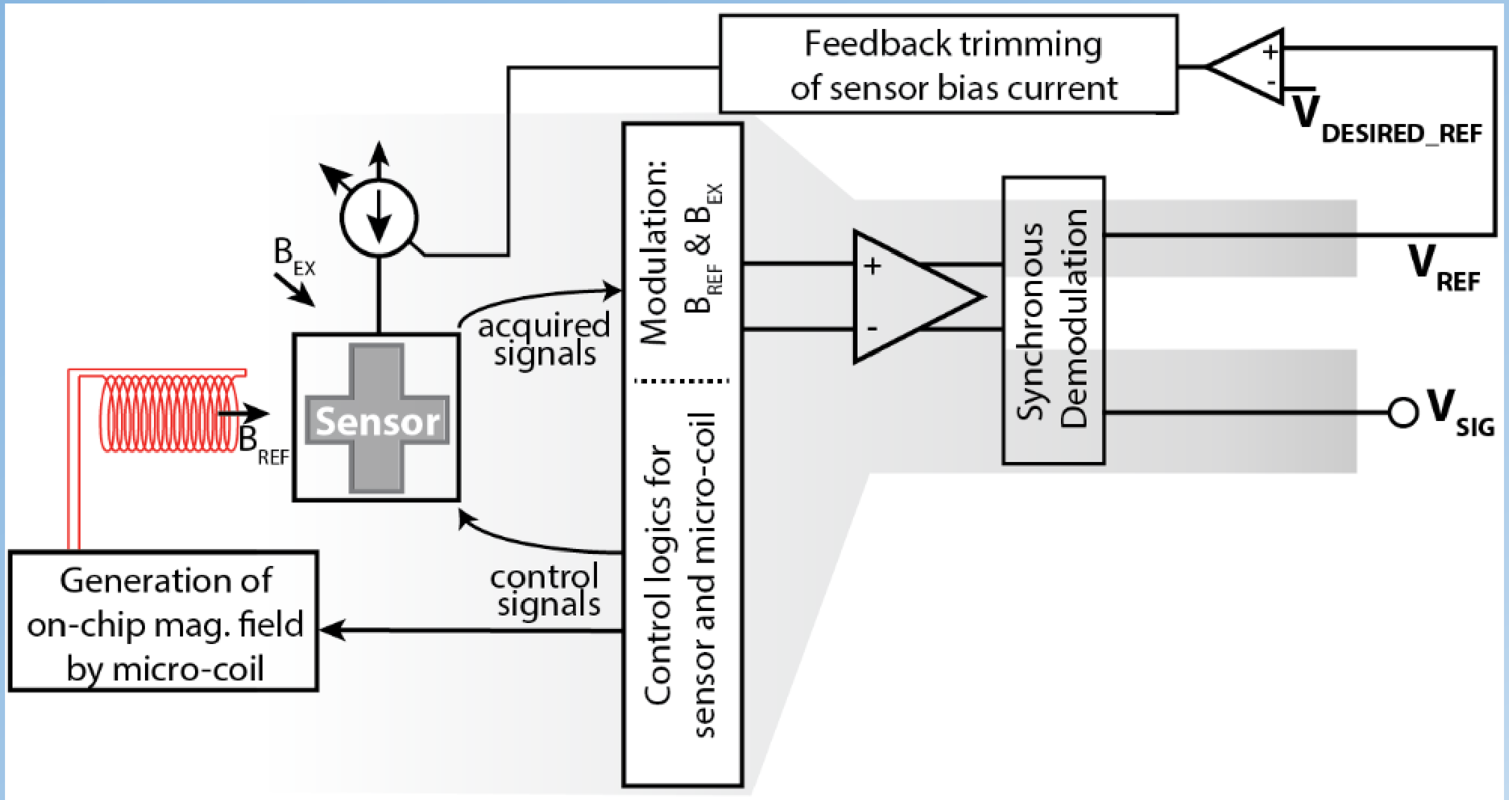
Motivation

- Microcoil (µCoil) used in System on Chip (SoC) where on chip magnetic field generation is desired
- Example is BIST (Build in Self Test)
- Characterization & compensation of magnetic field sensor (Magnetoresistors or Hall element) sensitivity
- On-chip generated magnetic field should be uniformly distributed
- Increasing demand for:
  - measurement precision
  - reliability



Developed for the ASIC

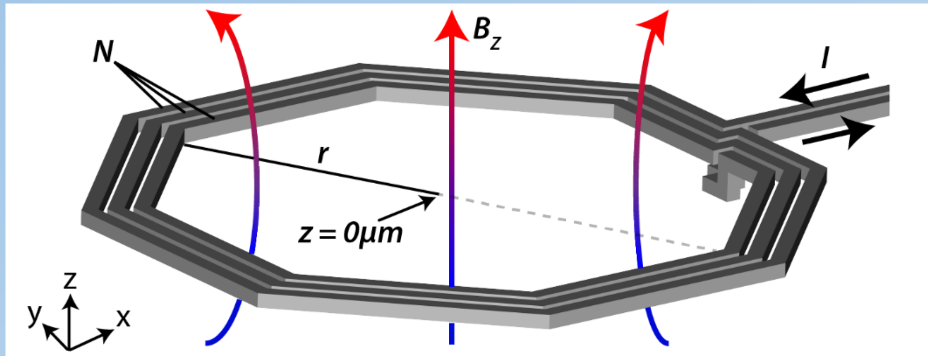
- Temperature compensated magnetic field sensor



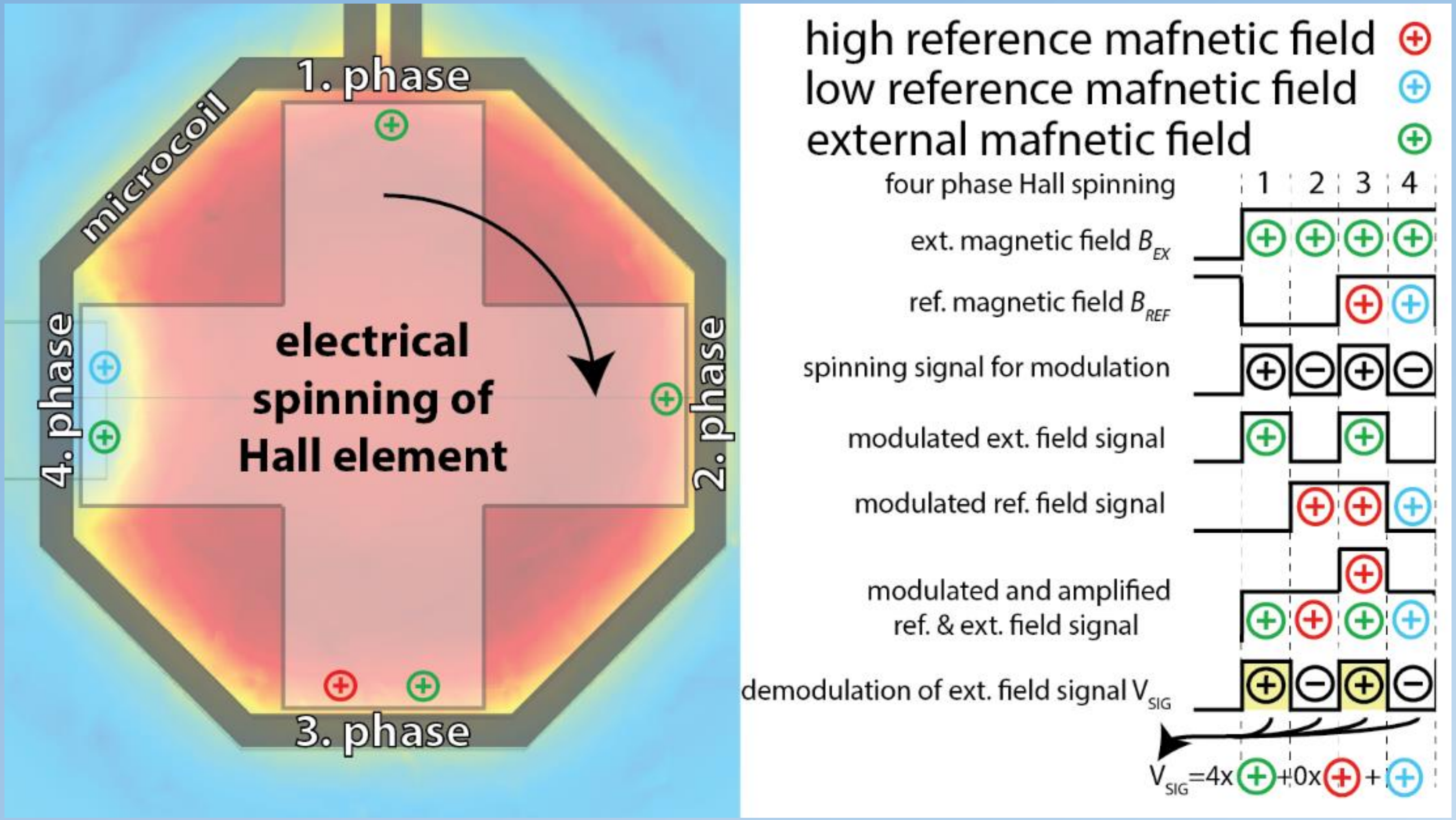
µCoil Optimization

- Two contradictory conditions (**optimization needed**):
  - **Produce high magnetic field B_z (higher bias current *I*)**
  - **Efficient µCoil with low heating**
- Produce uniformly distributed field
- Optimization parameters:

Control variable / Constraints	Symbol	Lower bound	Upper bound
µCoil radius	r	10 (µm)	50 (µm)
Number of µCoil turns	N	1	3

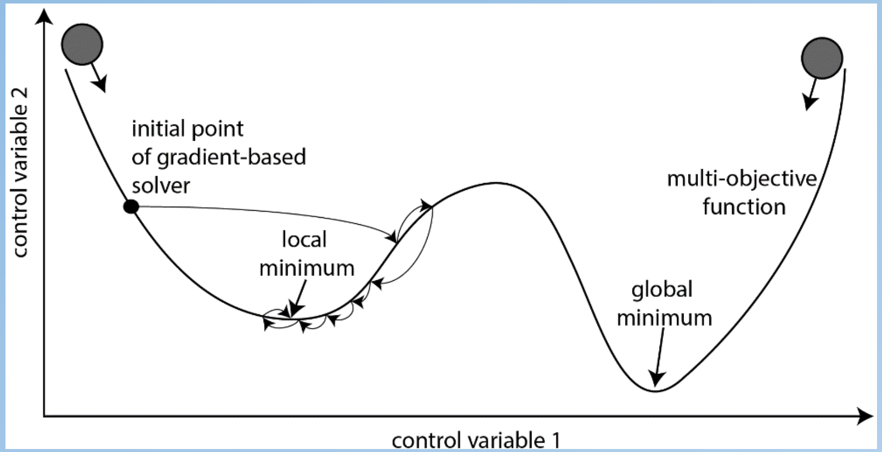


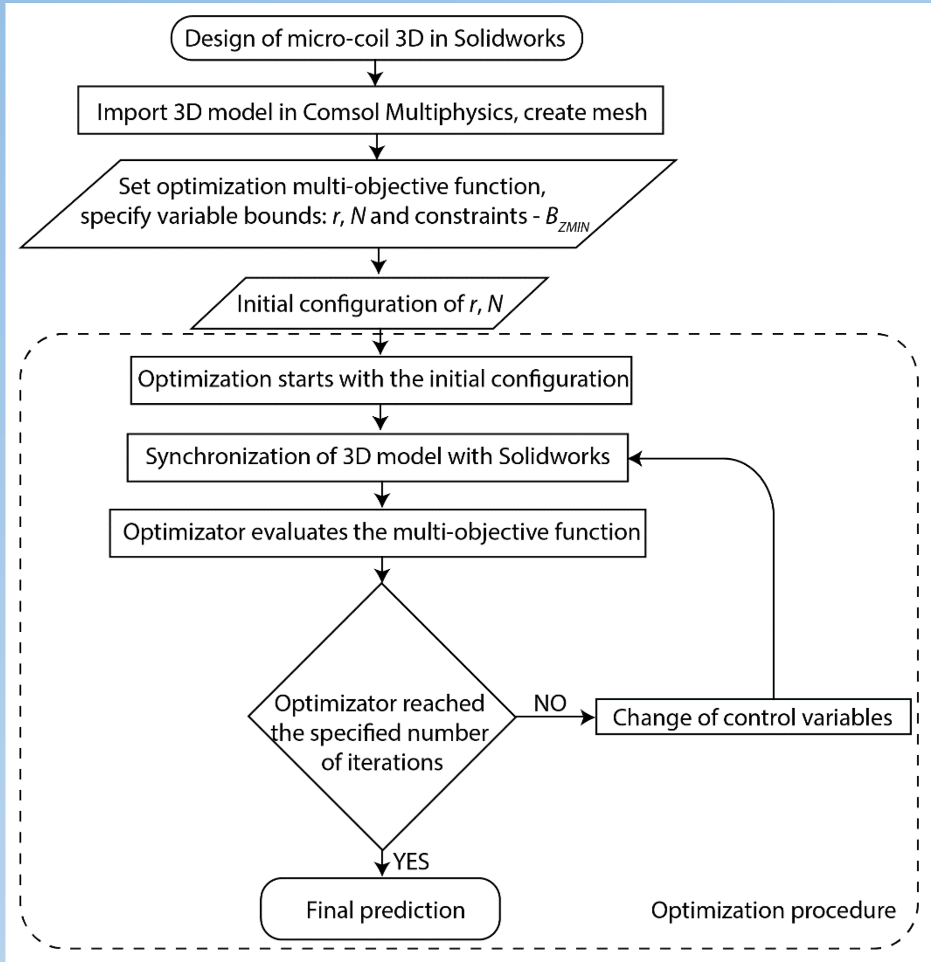
Why uniformly distributed magnetic field?



Optimization process

- Parametrized 3D model (Silodworks)
- Optimizator COMSOL Multiphysics
- Optimization in range of tech. parameters
- MonteCarlo approach (find global optimum)





Optimization process

- Multi-optimization problem composed of 3 objective functions:
  - Minimize µCoil resistance

$$Q_R = \frac{R_{COIL} - R_{MIN}}{R_{AVG}} * k_R$$

  - Minimize standard deviation of mag. field.

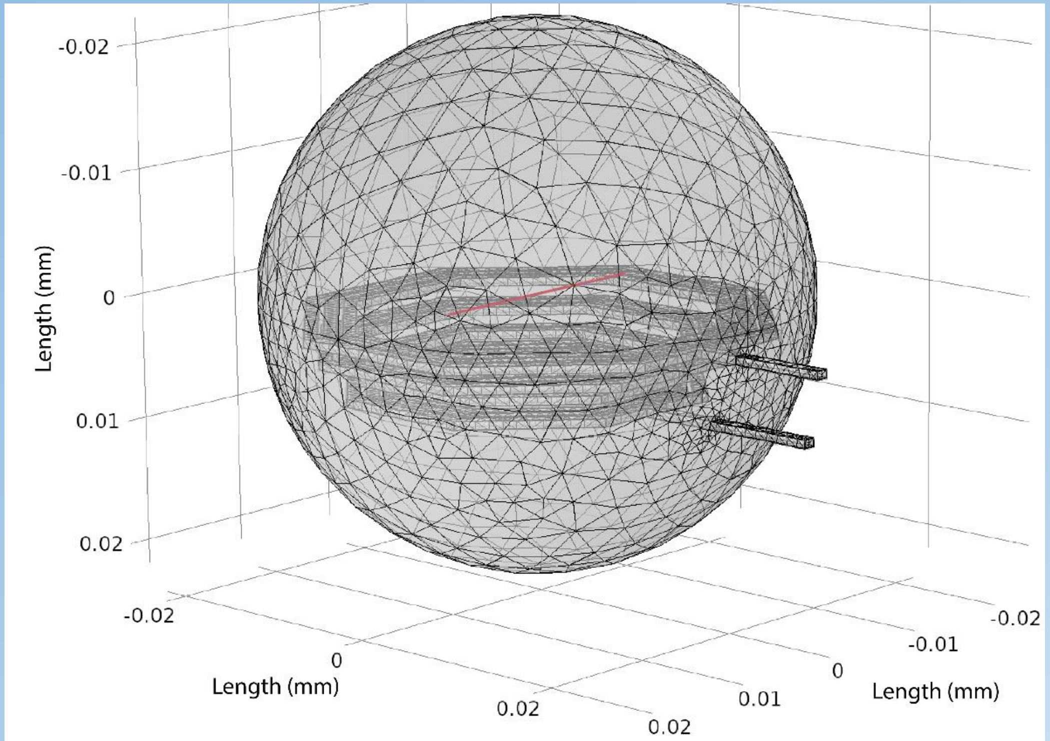
$$Q_{stdB} = \frac{\left(\frac{\sigma_B}{B_{Z0}}\right) - \left(\frac{\sigma_B}{B_{Z0}}\right)_{MIN}}{\left(\frac{\sigma_B}{B_{Z0}}\right)_{AVG}} * k_{stdB}$$

  - Assign desired significance to mentioned two objective functions:

$$Q_{combined} = abs(1 - \frac{Q_R}{Q_{stdB}}$$

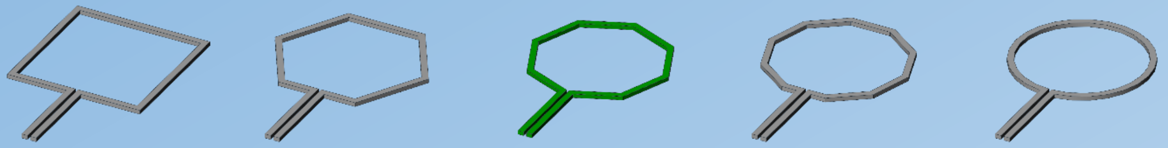
Optimization process

- Finite Element Method
- Mesh with high precision
- B_Z uniformity on the red line
  - Sensor location plane
- Additional constraint:
  - B_Z>1mT (not achievable at all planes)

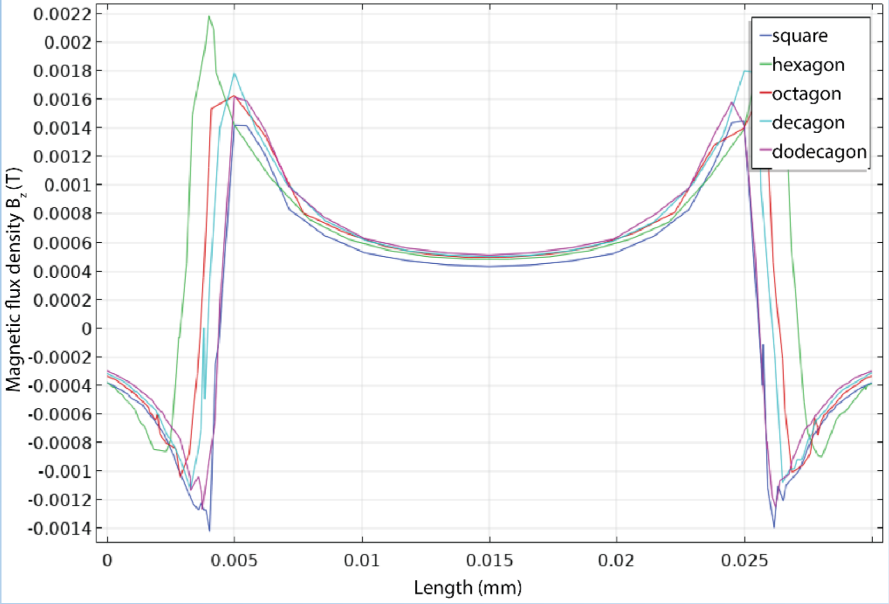


Shape of μCoil

- With respect to resistance and adoption to the maximum dimension of the Hall element, the octagon shape is chosen for the optimization process
- Limited to straight lines
- Minimal B_z deviation regarding shapes

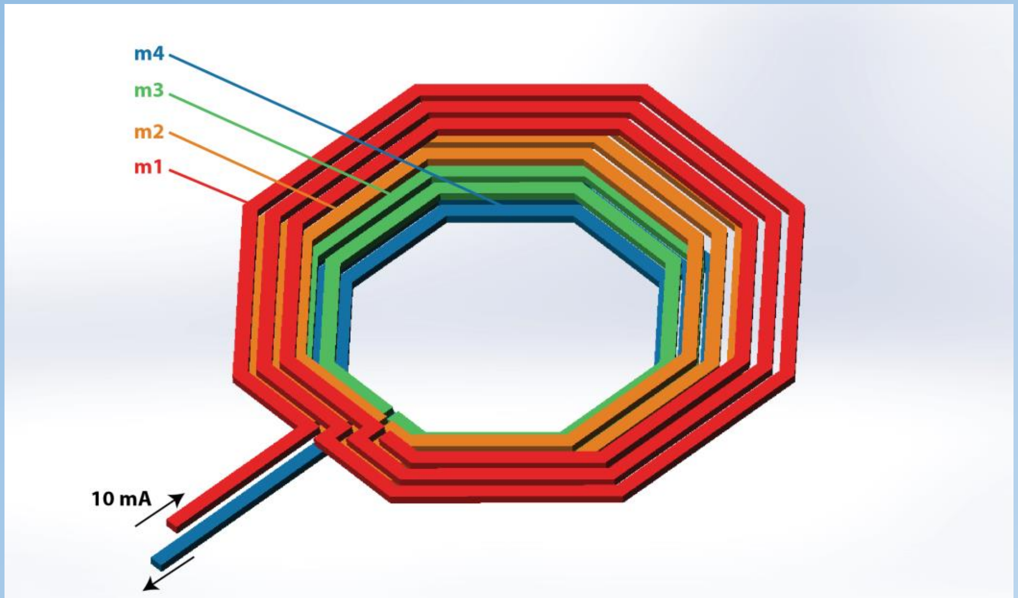


Number of μCoil sides	μCoil resistance (Ω)
4	4.40
6	3.98
8	3.84
10	3.82
12	3.76



Optimization solution

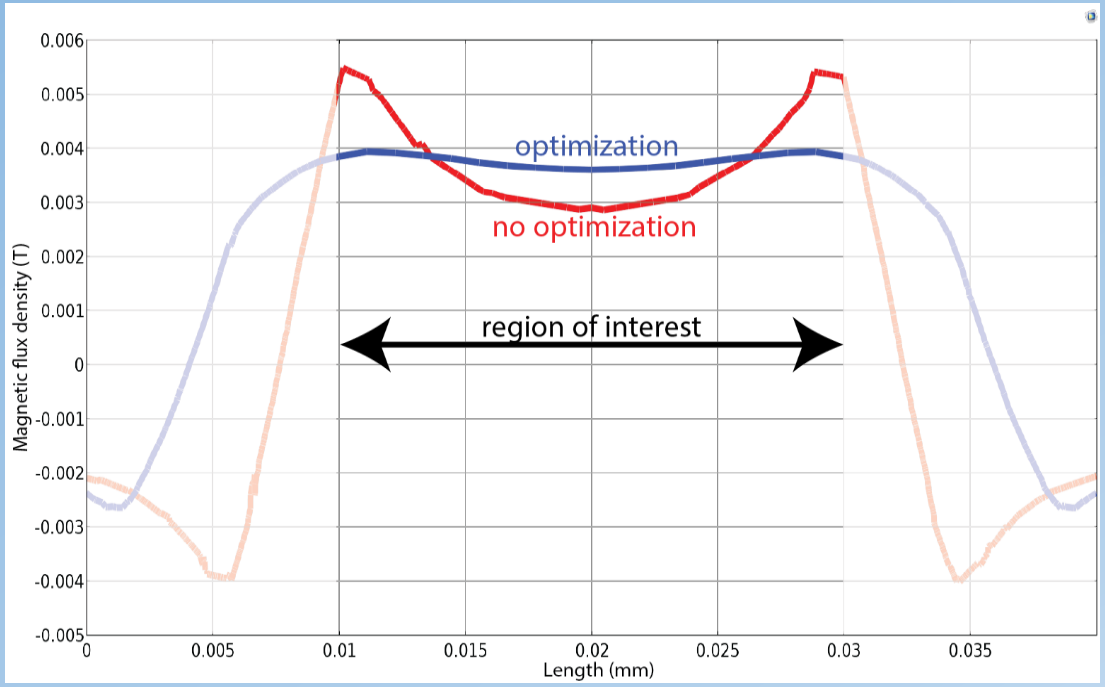
i	Metal layer	r_i (μm)	N	Q_R	Q_{stdB}	$Q_{combined}$	B_Z (mT)
1	m_i	14.3	3	0.253	0.413	1.053	1.017
2	m_i	12.2	3	0.209	0.363	0.998	1.055
3	m_i	10.6	2	0.084	0.049	0.860	0.643
4	m_i	10.0	3	0.159	0.330	1.007	0.646



Acquired optimized 3D model of the planar μCoil realized at four metal layers.

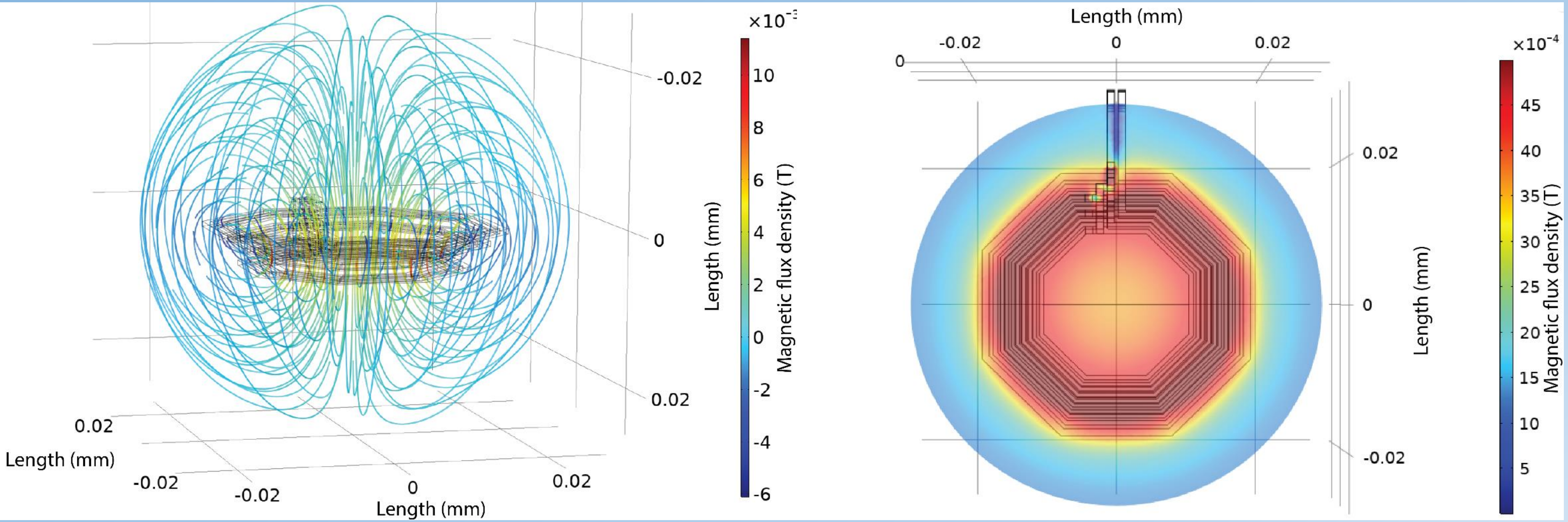
Optimized vs. non-optimized model of µcoil

- Both coils are designed to produce approximately the same average magnetic flux density of B_Z=3.76mT



Distribution of uniform magnetic flux density

- Streamline of magnetic flux density in the volume of simulation
- Distribution of magnetic flux density in plane of Hall sensor



Conclusions

- Optimization of CMOS µcoil in terms of efficiency (min. thermal looses) and performance (maximize the uniformity of the magnetic field in the plane of the sensor)
- Developed for the temperature compensated ASIC where on-chip reference magnetic field generation is desired
- Multi-objective function with objectives, taking into account CMOS technology rules
- Generation of approximately B_Z=3.76mT of average magnetic flux density

Thank you for your attention