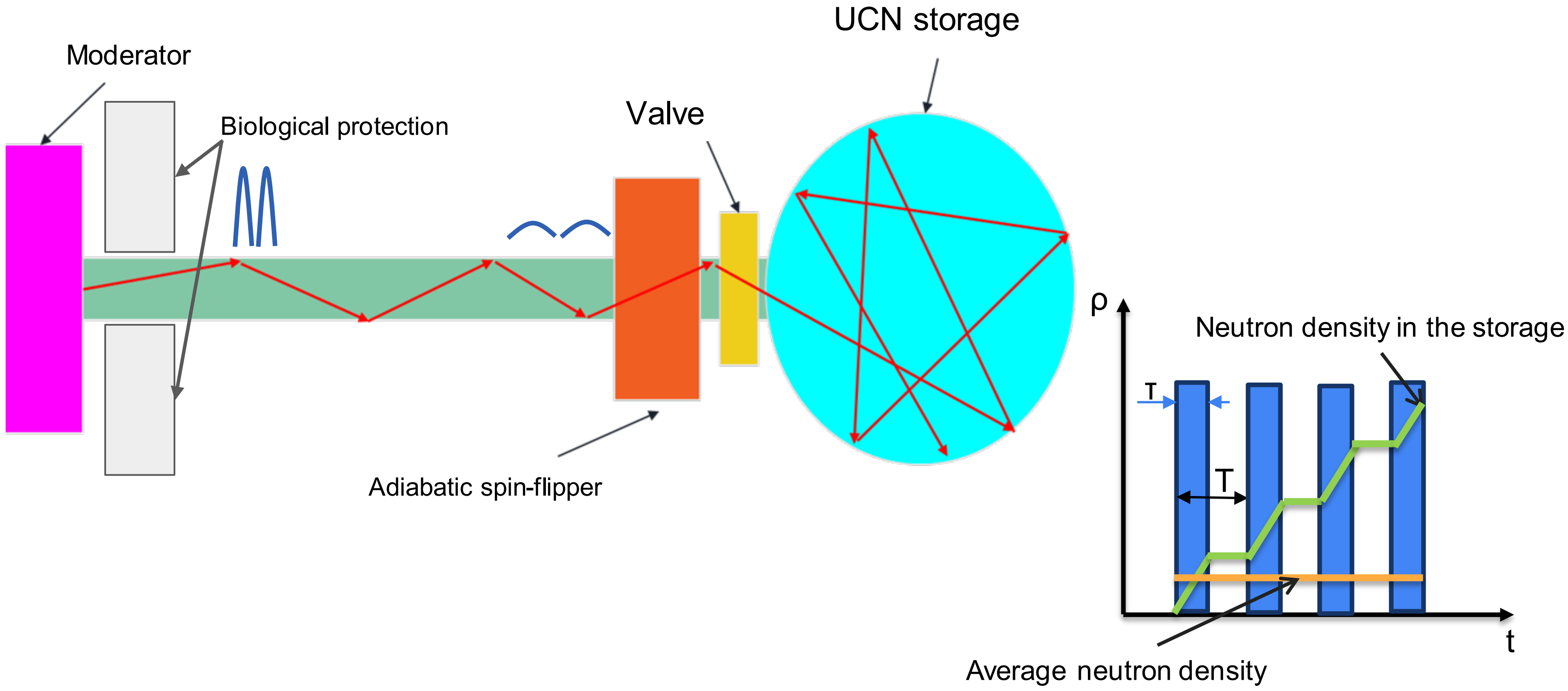
Birdcage resonator for a gradient spin flipper in strong magnetic fields

V.A. Kurylev, G.V. Kulin

Pulsed UCN source



Adiabatic spin flipper

G. M. Drabkin. Production of Supercold Polarized Neutrons/G. M. Drabkin and R. A. Zhitnikov//Журнал Экспериментальной и Теоретической Физики, 38(1013), 1960

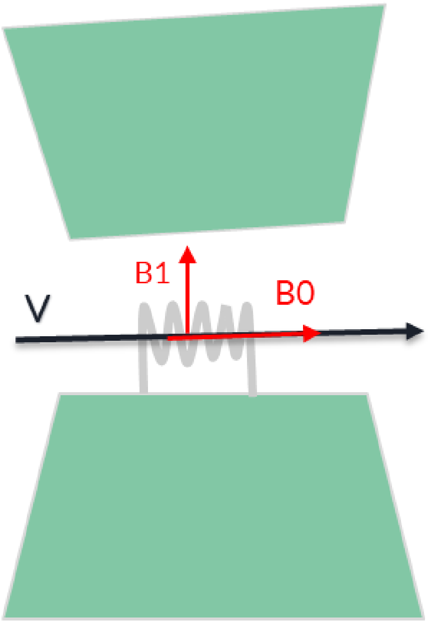
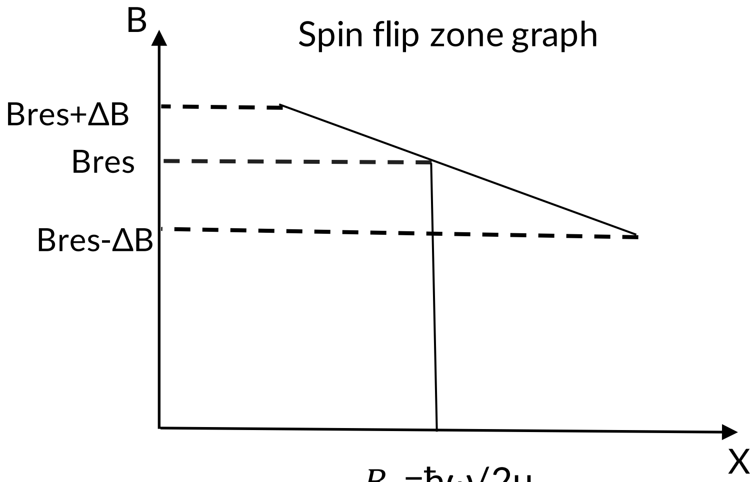


Diagram of the magnetic sistem



Spin flip zone graph

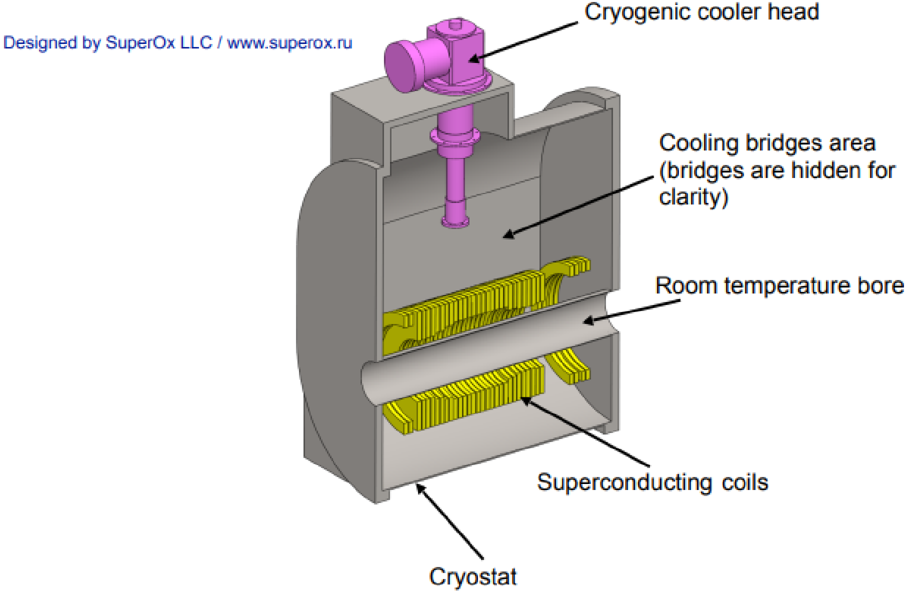
$B_0 = \hbar\omega / 2\mu$

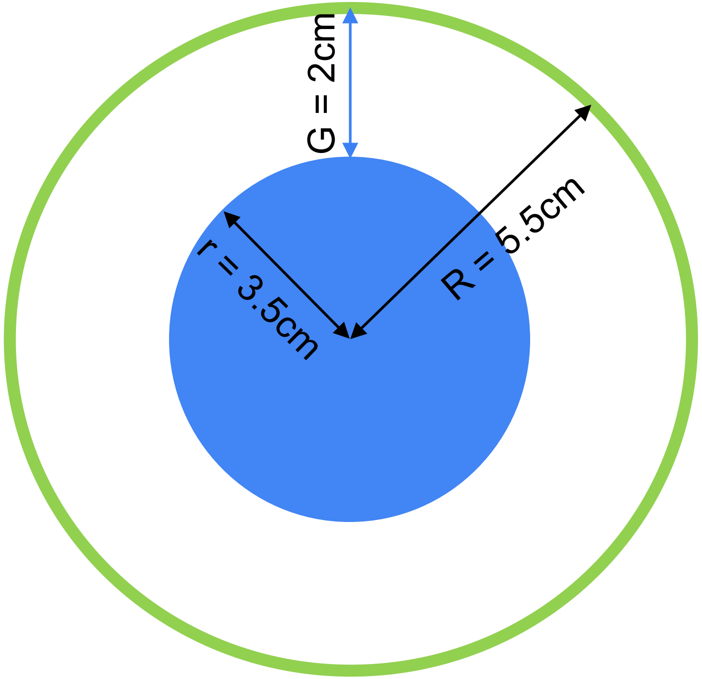
$\Delta B \gg |B1|$

$\Delta E = 2\mu B_{res}$

Superconducting magnet

Preliminary magnet design

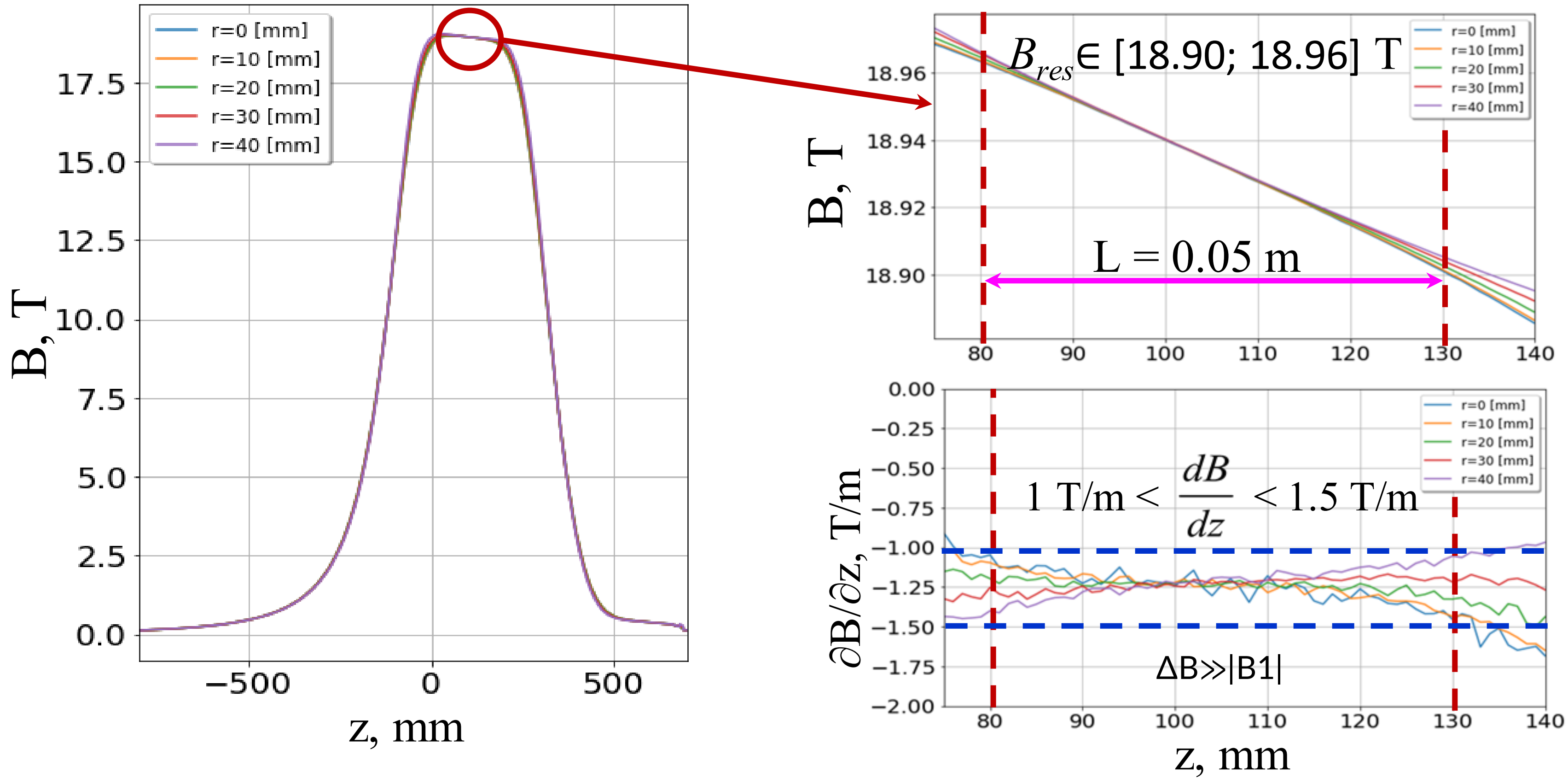




Design of the solenoid magnet made of superconducting tape

Spin flip zone

4



$B_{res} \in [18.90; 18.96]$ T

L = 0.05 m

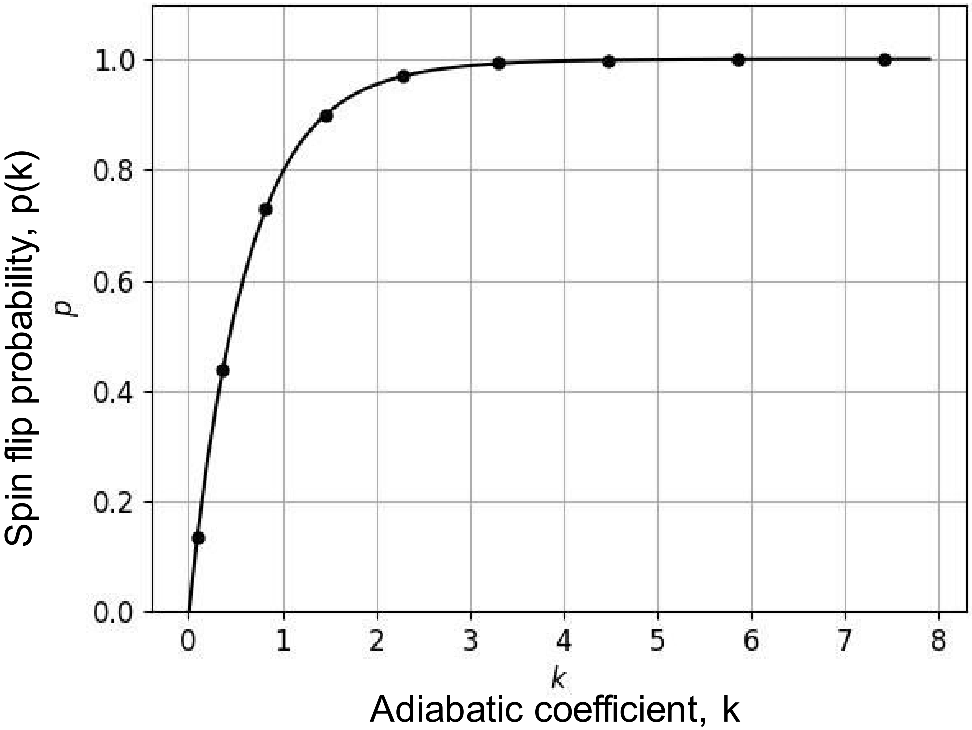
$1\ \text{T/m} < \dfrac{dB}{dz} < 1.5\ \text{T/m}$

ΔB≫|B1|

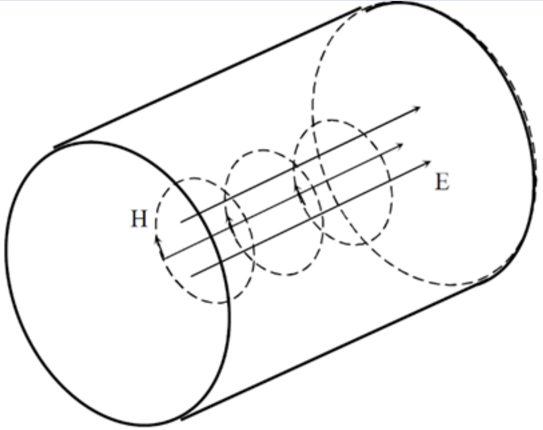
Adiabaticity parameter

$$k = \frac{\gamma B_1^2}{(dB/dz)V},$$

γ - gyromagnetic ratio (1.83*10^8[1/(T*s)]),
B_1- amplitude of alternating magnetic field,
dB/dz - gradient of constant field in the spin flip region,
V - speed of a neutron when it enters a spin-flipper field (~15 [m/s])

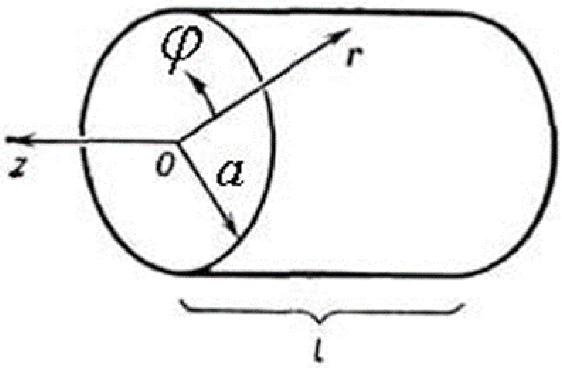


Volumetric resonator



Field pattern E010 inside the volume of a cylindrical resonator

Calculation of resonator dimensions



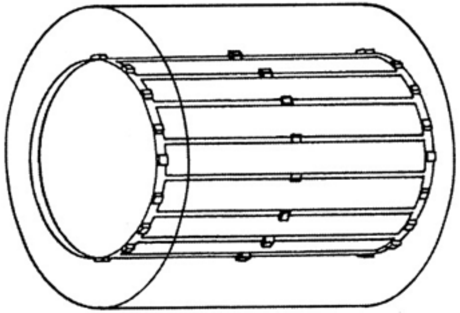
$$l = \frac{\lambda}{2} = \frac{c}{2f} = \frac{3}{10} = 0.3\,m$$

$$\omega_{010} = \frac{1}{\sqrt{\varepsilon\mu}} * \frac{\nu_{01}}{a}, \nu_{01} = 2.4048$$

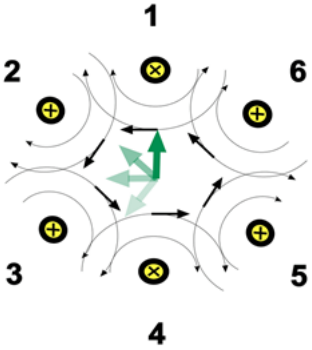
$$a = \frac{\nu_{01}}{(2\pi\sqrt{\varepsilon\mu})} = 0.28m = 28cm$$

$$\boxed{a > 5.5cm\ (R)}$$

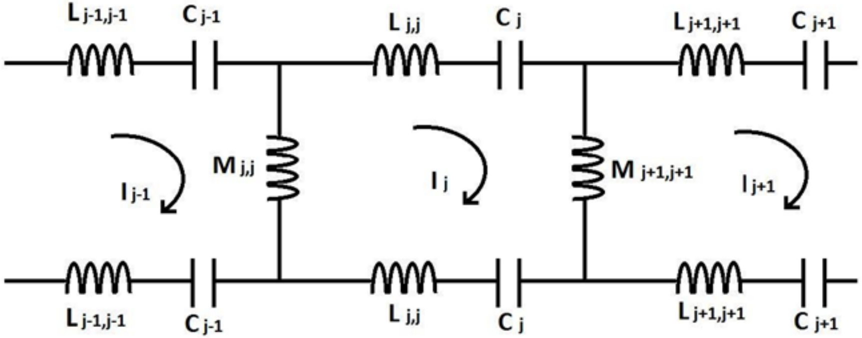
Birdcage coil



General view of the "Birdcage"



Field type B1



Equivalent circuit

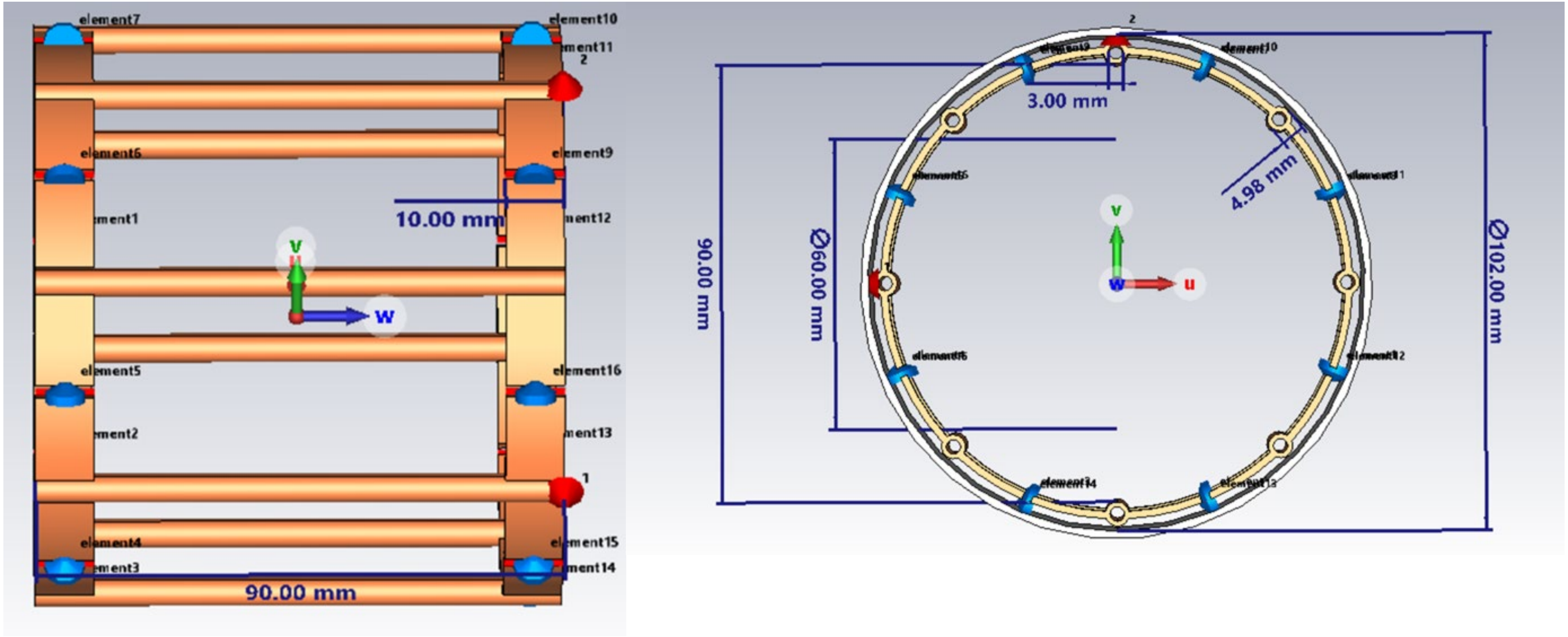
$$L = \frac{\mu_0 l_{er}}{2\pi}\left(\ln\left(\frac{2l_{er}}{w}\right)+\frac{1}{2}\right),$$

$$M = \frac{\mu_0 l_l}{2\pi}\left(\ln\left(\frac{2l_l}{r_{out}}\right)+(0.1493n^3-0.3606n^2-0.0405n+0.2526)-1\right),$$

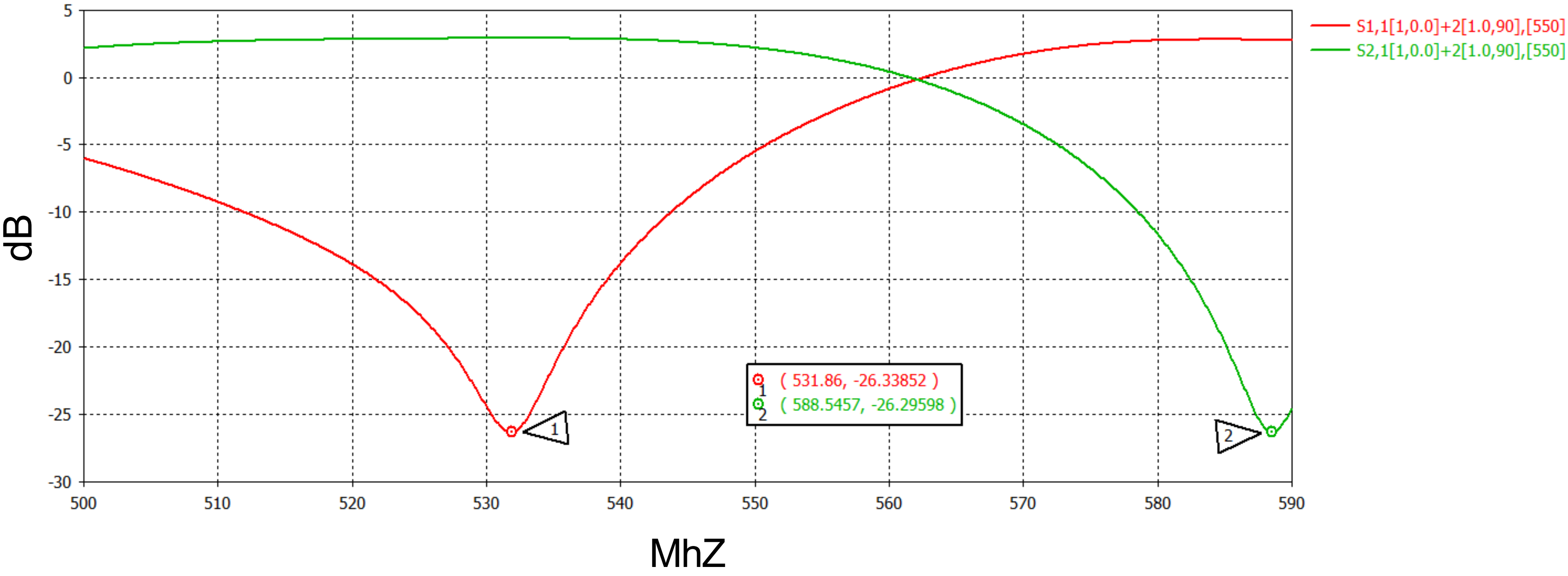
$$\omega = \sqrt{\frac{1}{C\left(L+2M\sin^2\frac{\pi m}{N}\right)}},\ m=0,1,\ldots,N/2+1$$

$$\mathrm{C}=\frac{1}{\omega^2\left(L+2M\sin^2\frac{2\pi m}{N}\right)}$$

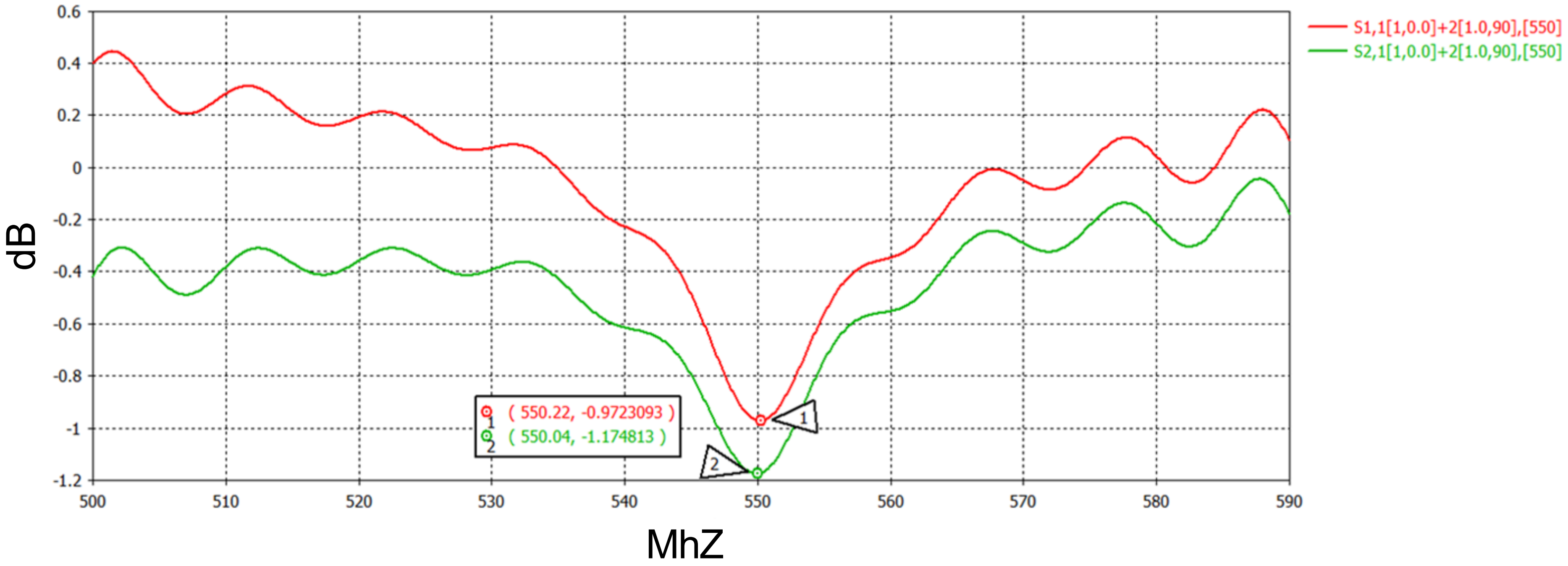
Resonator model



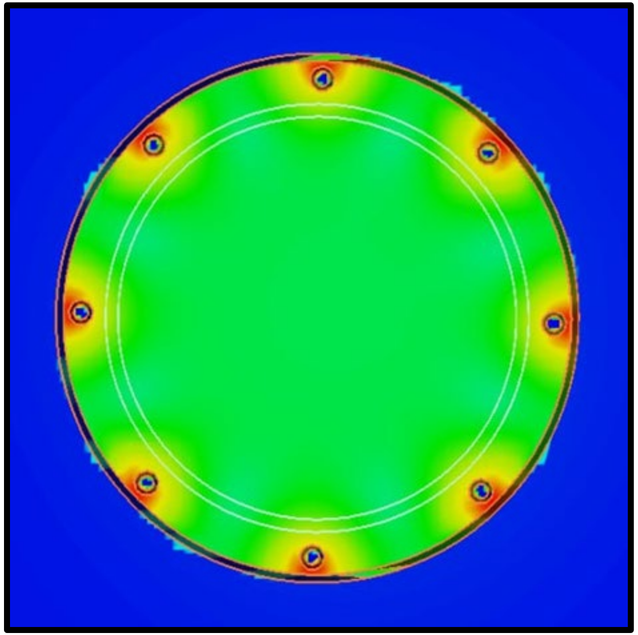
Optimization



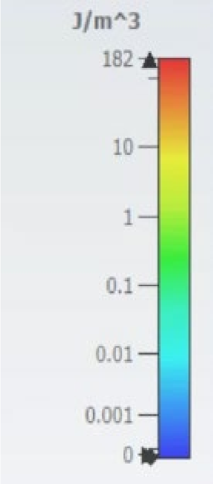
Loss parameters (S-parameters), at C = 7.29 pF

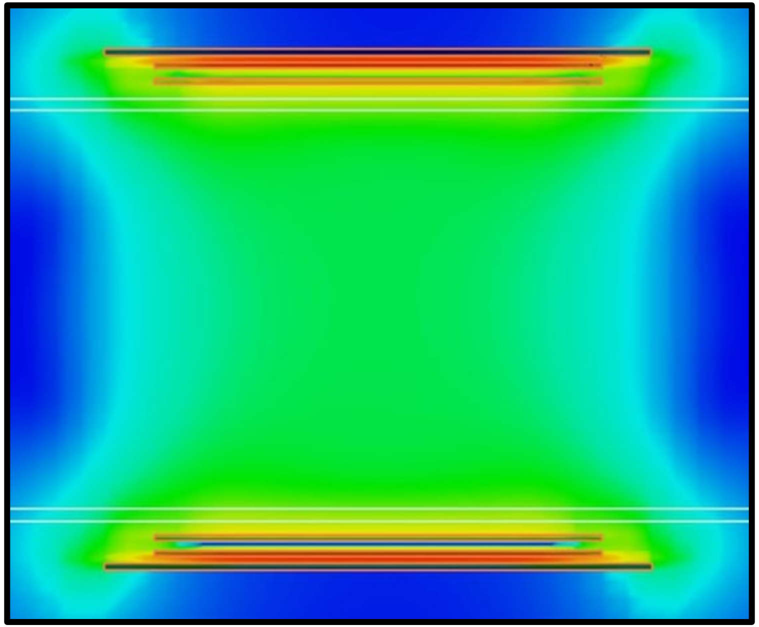


Distribution of magnetic energy



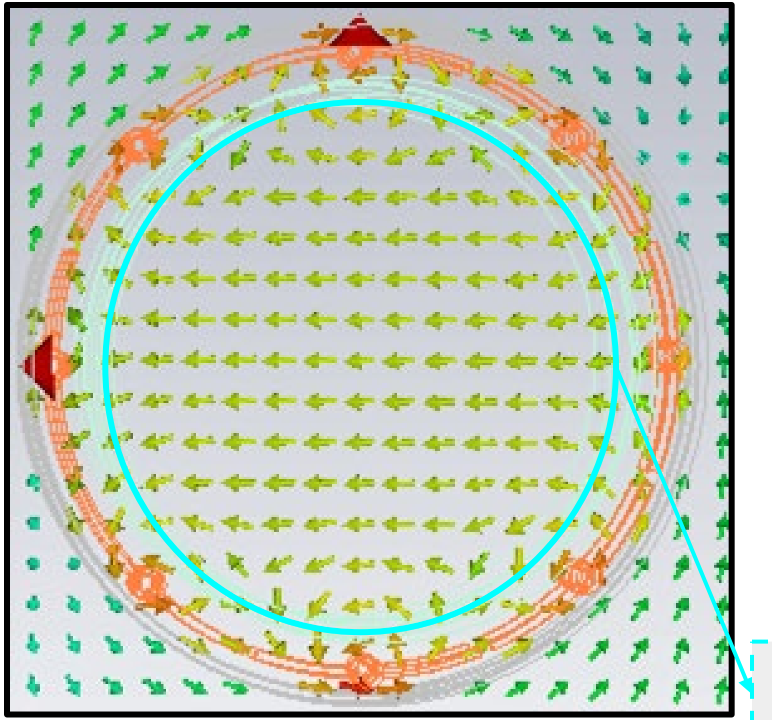
Distribution of magnetic field energy in the resonator cross section

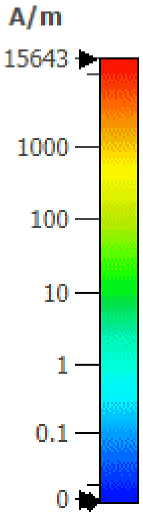


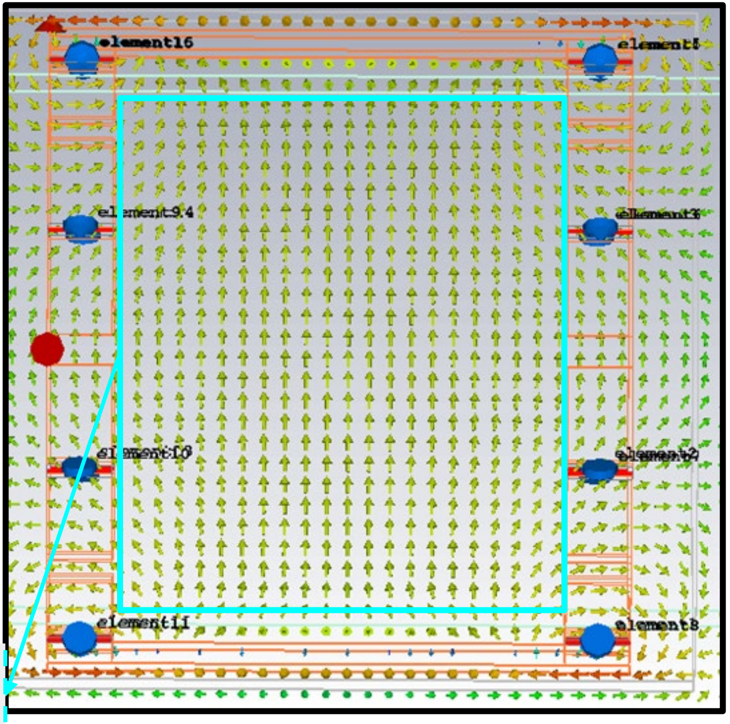


Magnetic field energy distribution profile

Precession of the magnetic field B_1







Useful volume

Field in the cross section of the resonator

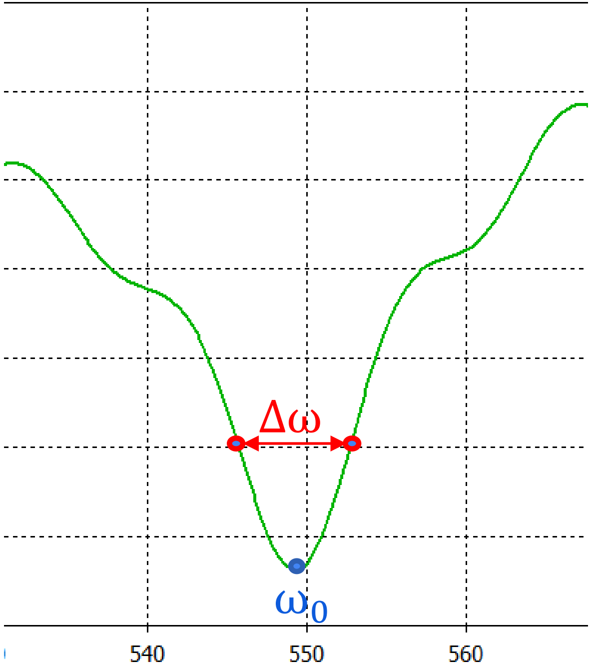
Field in the resonator volume

Power calculation

$$Q = \omega * \frac{E}{P} = \frac{\omega L}{R}; \mathrm{Q} = \frac{\omega_0}{\Delta\omega} = 40.5639$$

$$R = 4\Omega$$

$$J_m = \frac{2R_{er}B_1}{\mu_0} = 43\ A$$



$$P = J_m^2 * R = 5.5\ kW$$

$$P = \frac{2\pi}{3}\mu_0\Lambda_1^2\frac{\omega^4}{c^3}R_{er}^2 l_l^2 = 5.2\ kW, \qquad \Lambda_1 = \frac{J}{2\pi R_{er}}$$

$$\boxed{P \approx 5.5\ kW}$$

Summary

- *The geometric parameters of a hollow round resonator were obtained, from which it follows that it is impossible to install it in the light of an adiabatic spin-eraser without significant changes in the design of the superconducting magnet.*
- *The required resonator capacity, suitable geometric and frequency conditions of installation were calculated.*
- *A resonator model was created, simulation and fine-tuning were carried out in the CST Studio Suite program environment. A primary calculation of the stationary mode power was made.*
- *A concept of an RF resonator suitable for further use in an adiabatic spin-flipper device in a strong magnetic field was developed.*

Thank you for your attention!

FLnP

Spin precession

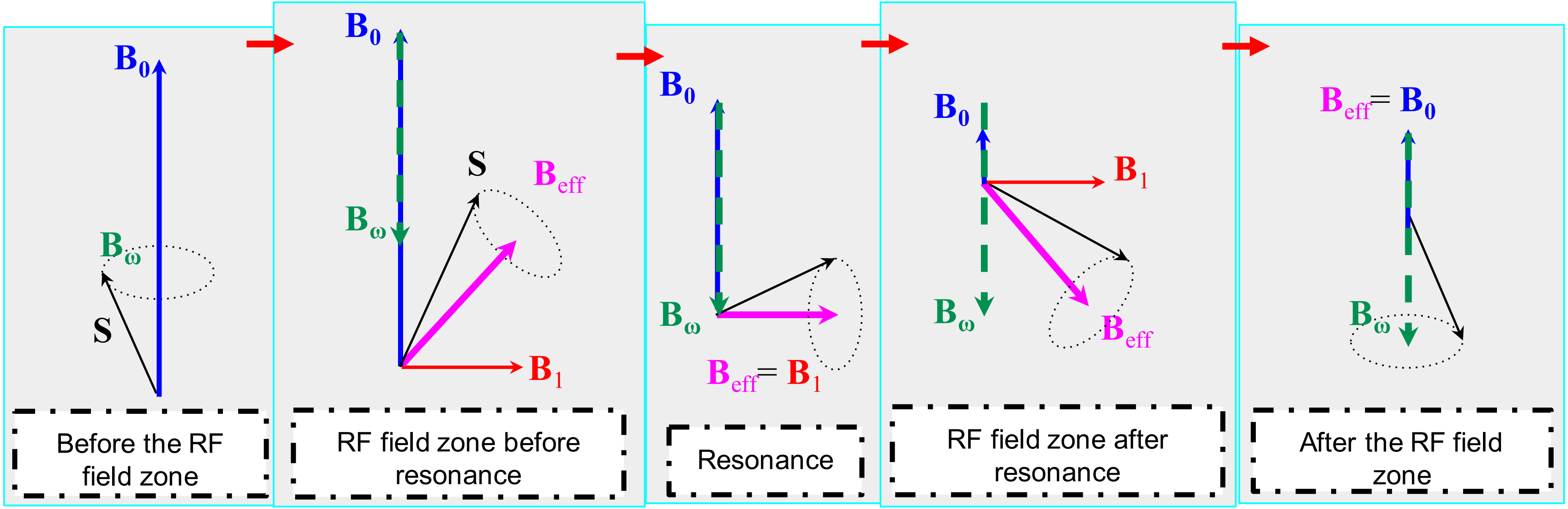
$B_0 = B_0^{start} + z\,\partial B/\partial z$ - gradient stationary field ($\partial B/\partial z < 0$)

$B_1 = B_1$ - alternating RF field with constant amplitude and rotation frequency ω, $B_1 \perp B_0$

$B_\omega = -\omega/\gamma$ – fictive field

$B_{eff} = B_0 + B_\omega + B_1$ - effective field

S - polarization



Before the RF field zone

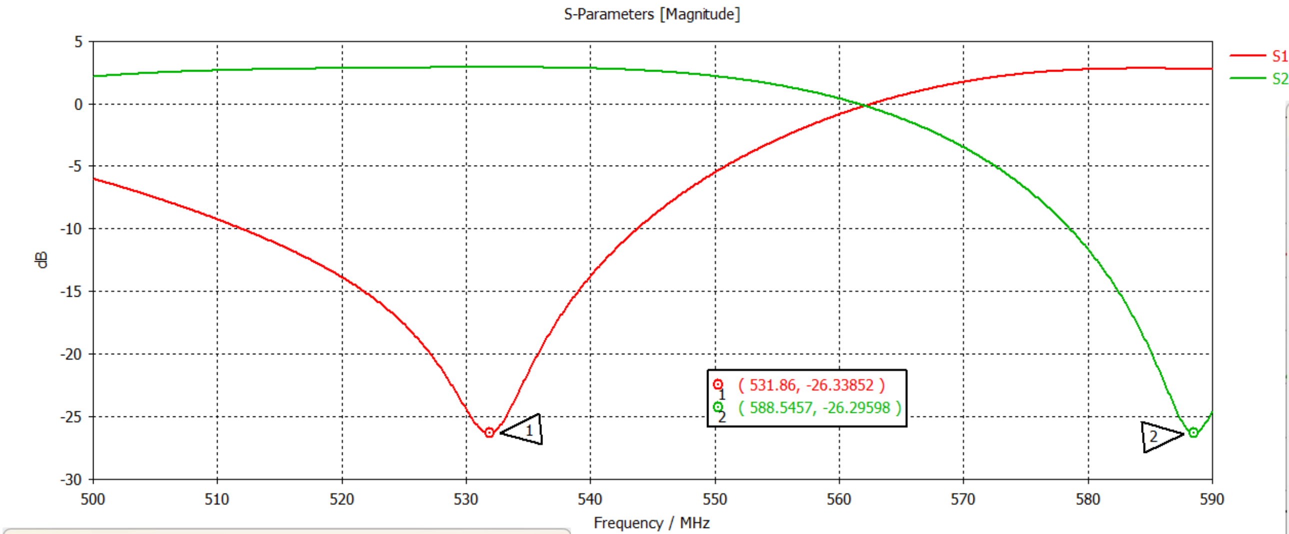
RF field zone before resonance

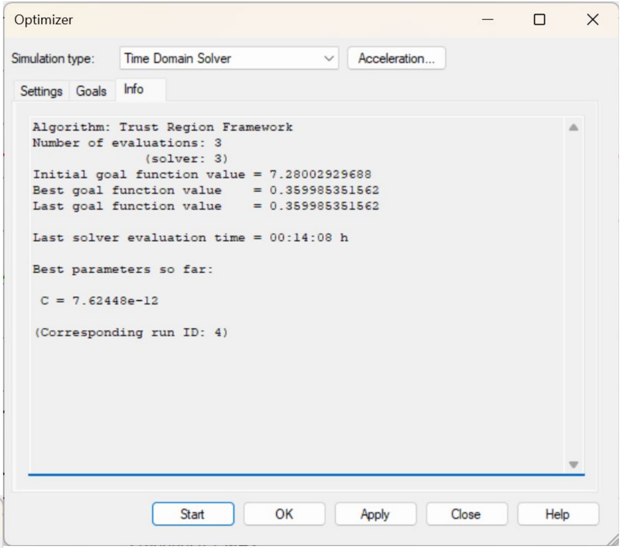
Resonance

RF field zone after resonance

After the RF field zone

Optimization





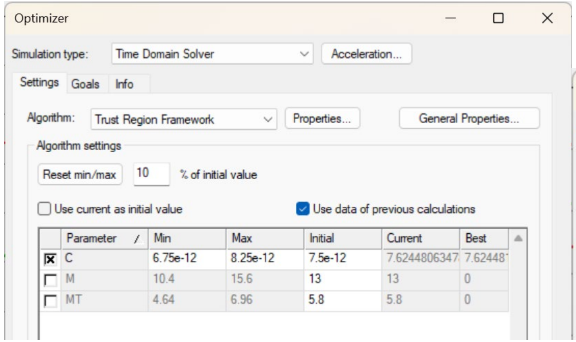
```
Algorithm: Trust Region Framework
Number of evaluations: 3
                (solver: 3)
Initial goal function value = 7.28002929688
Best goal function value    = 0.359985351562
Last goal function value    = 0.359985351562

Last solver evaluation time = 00:14:08 h

Best parameters so far:

 C = 7.62448e-12

(Corresponding run ID: 4)
```



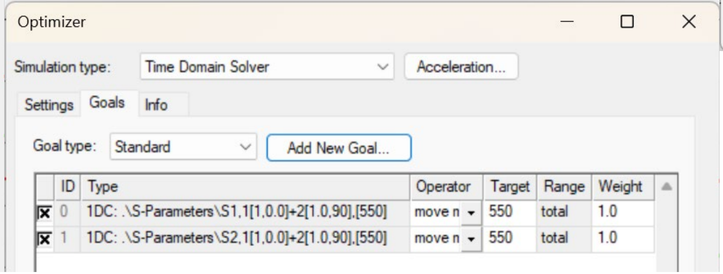
Algorithm: Trust Region Framework

10 % of initial value

☐ Use current as initial value

☑ Use data of previous calculations

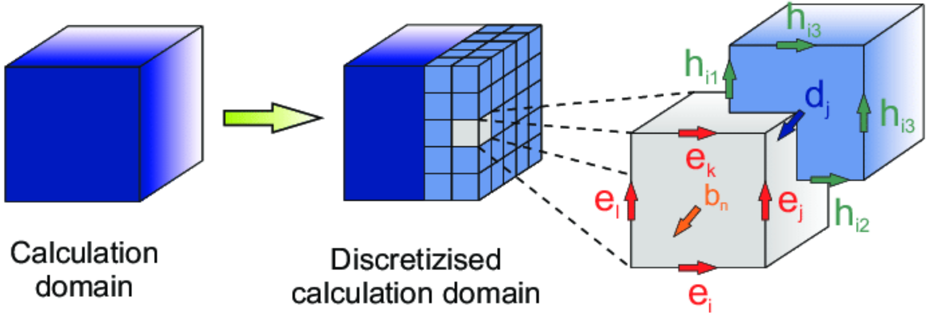
	Parameter	Min	Max	Initial	Current	Best
☒	C	6.75e-12	8.25e-12	7.5e-12	7.6244806347	7.62448
☐	M	10.4	15.6	13	13	0
☐	MT	4.64	6.96	5.8	5.8	0



Goal type: Standard

	ID	Type	Operator	Target	Range	Weight
☒	0	1DC: .\S-Parameters\S1,1[1,0.0]+2[1.0,90],[550]	move n	550	total	1.0
☒	1	1DC: .\S-Parameters\S2,1[1,0.0]+2[1.0,90],[550]	move n	550	total	1.0

CST studio suite



h_{i1}: Magnetic voltage
e_{i1}: Electric voltage
d_i: Electric flux
b_n: Magnetic flux

Finite integration method

$$\oint \vec{E}(\vec{r},t)d\vec{s} = -\iint \frac{\delta}{\delta t}\vec{B}(\vec{r},t)d\vec{A}\ \forall\ A \in \Re^3$$

Faraday's law in integral form