Garnet Sample Permeability Measurement

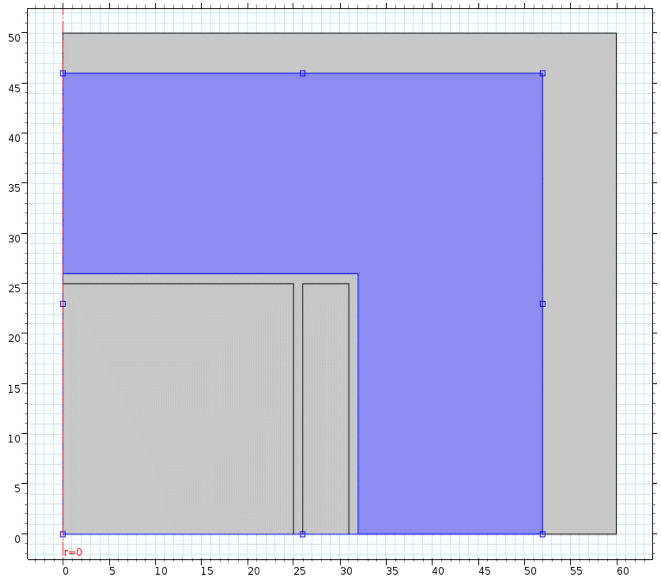
Magnet Design Study

Main goals of this study is

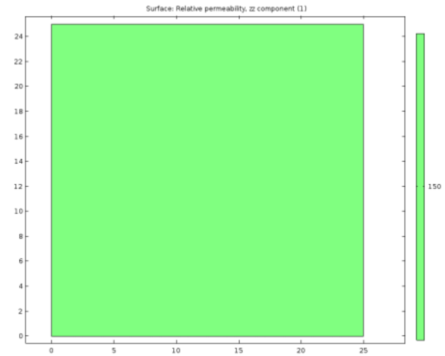
- To understand a set of requirements for the measurement system (to measure magnetization curves of garnet material samples)
- To suggest a simple setup that would allow making the measurements.

Axially Symmetric Model

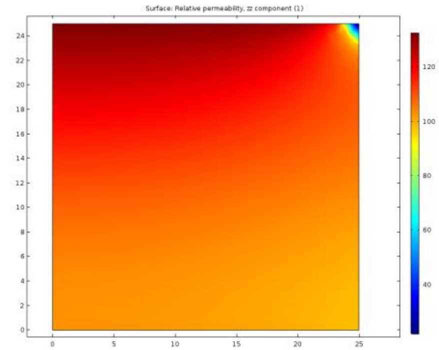
N = 50



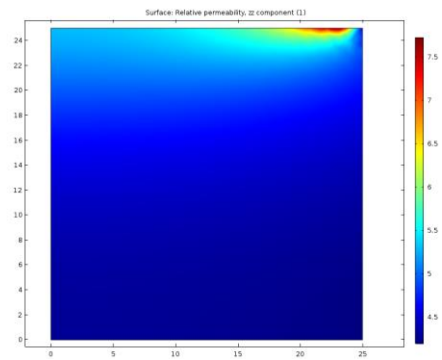
0.1 A



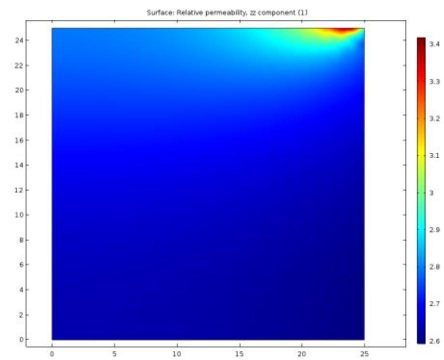
1 A



10 A



20 A



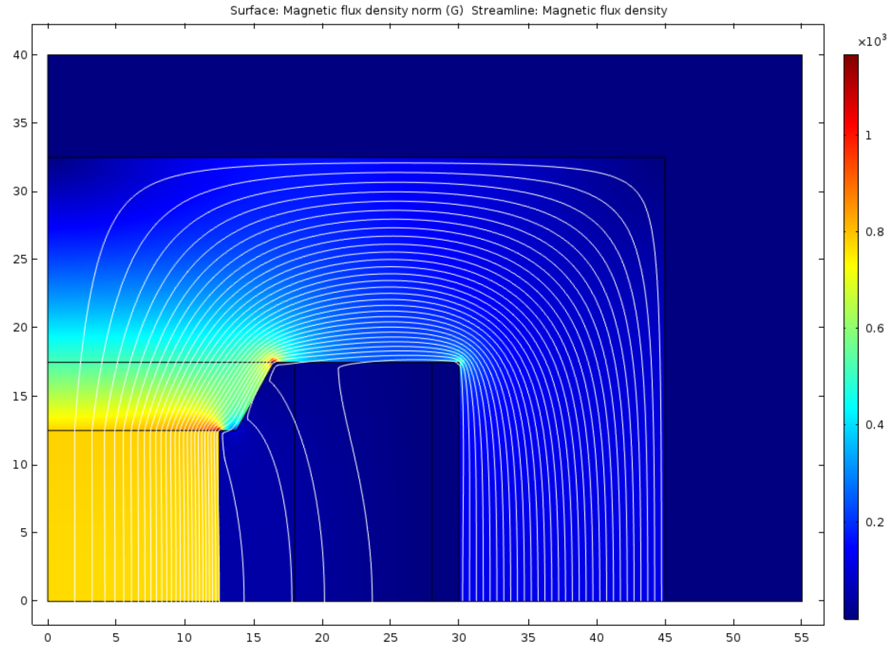
Permeability range in the sample is ~15% @ 20 A to ~30% @ 1 A

Field distribution in the garnet material is not uniform due to:

1. Finite permeability of the flux return
2. A gap between the pole and the sample

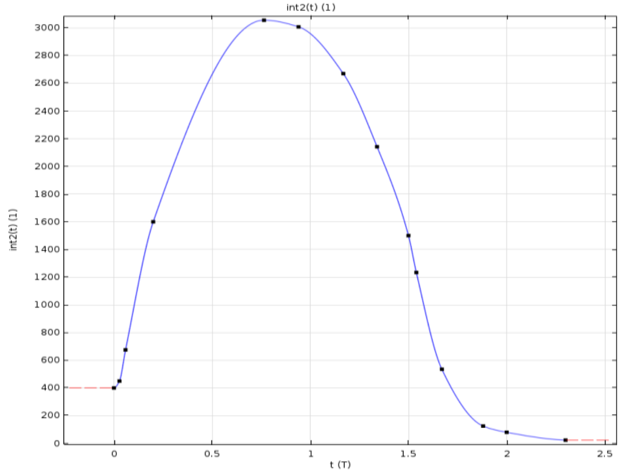
Optimizing the geometry

One of reasons of field non-uniformity in the sample is its configuration in the gap. It can be changed by adjusting the profile of the pole and position and size of the excitation coil.

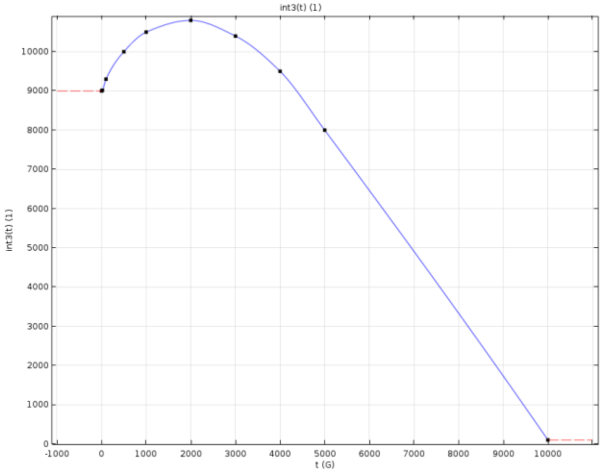


Magnetic properties of the flux return are important

Low-carbon steel

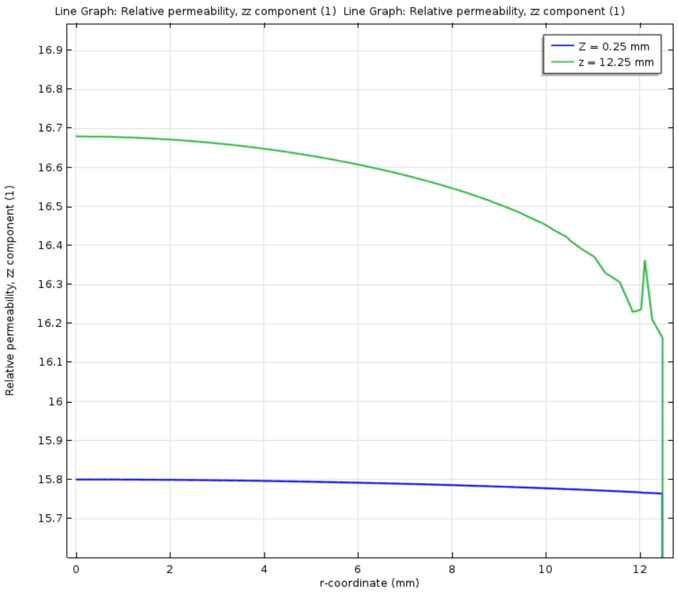


MN100 ferrite



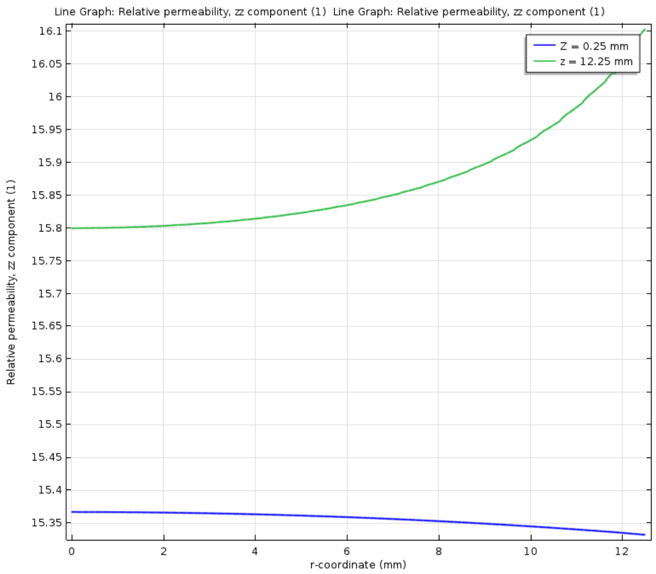
Choosing material for the FR

Low Carbon Steel



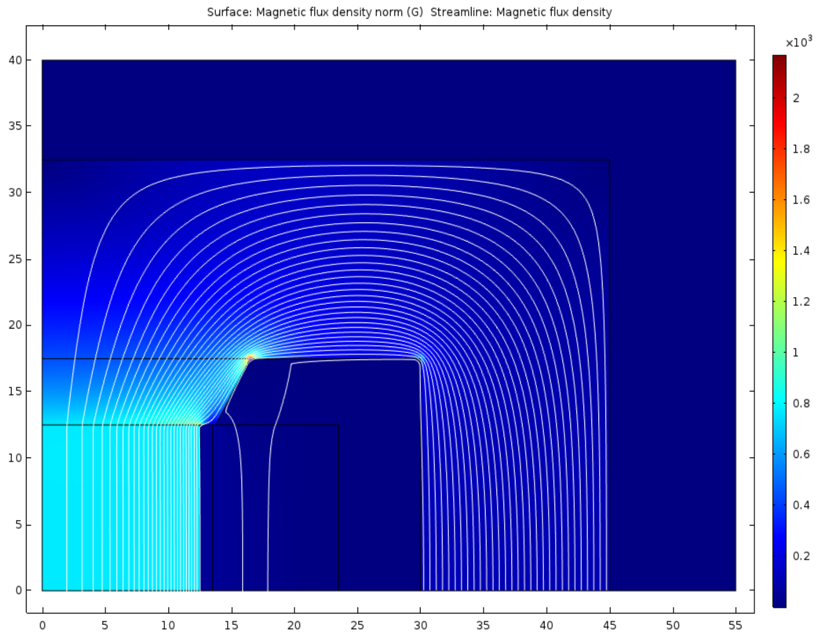
At 2 A:
Volume average μ - 16.0
Range 15.75 – 16.75 (6.3%)
∫H*dl @ r = 0 47.98 A
∫H*dl @ r = 12.5 mm 48.33 A

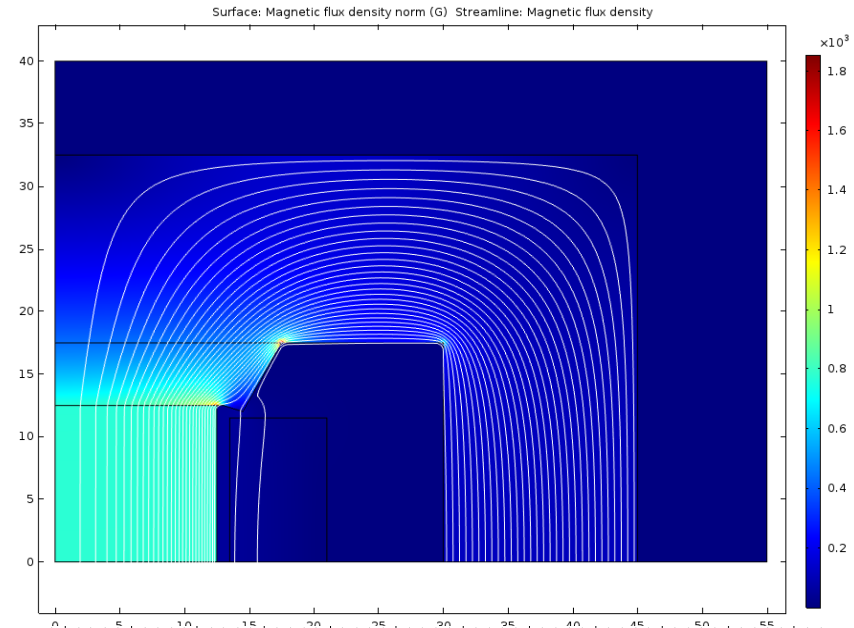
μ = 5000



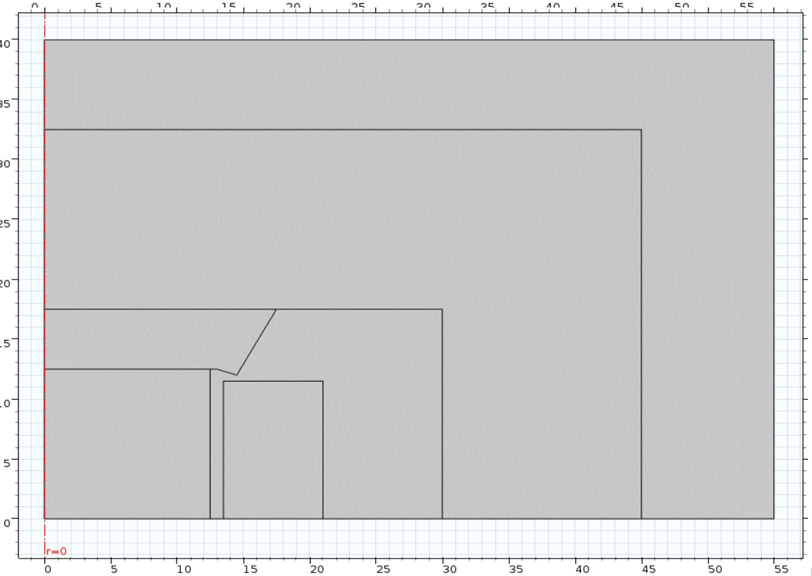
At 2 A:
Volume average μ - 15.53
Range 16.11 – 15.35 (3.8%)
∫H*dl @ r = 0 49.80 A
∫H*dl @ r = 12.5 mm 49.84 A

Position and size of the coil and pole shape

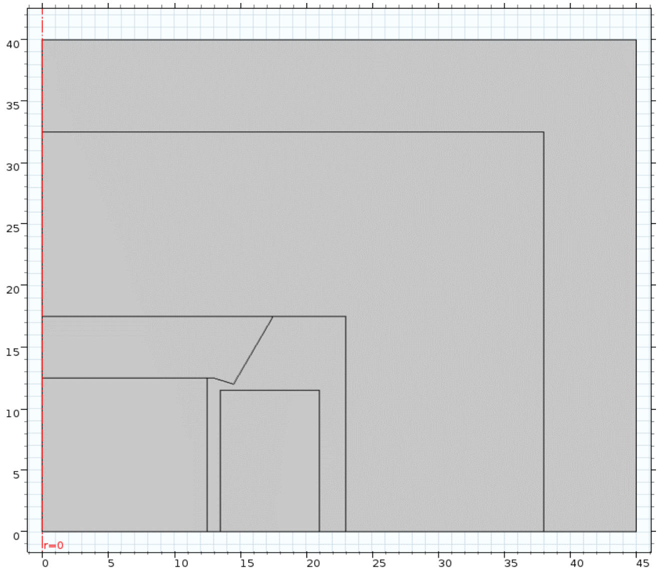




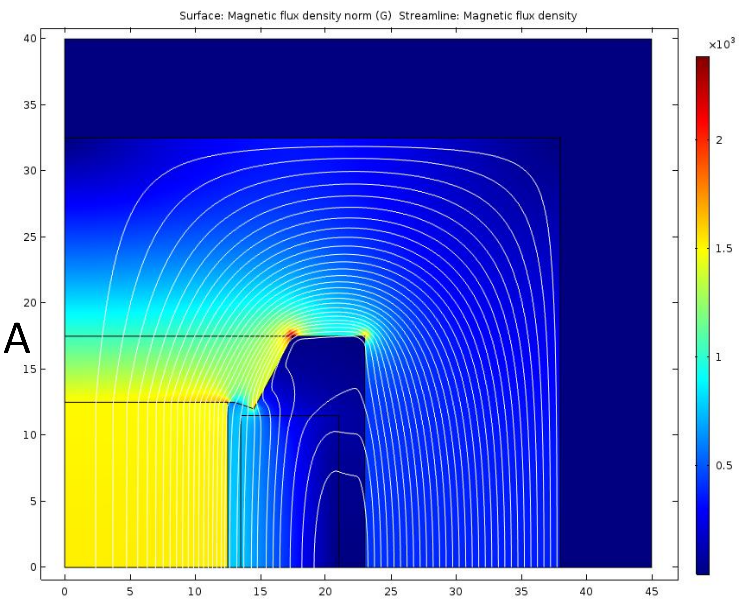
Field distribution changes as the excitation current increases. Magnetic circuit optimization must be made at an intermediate current and checked at the minimum and maximum. 2 A optimization



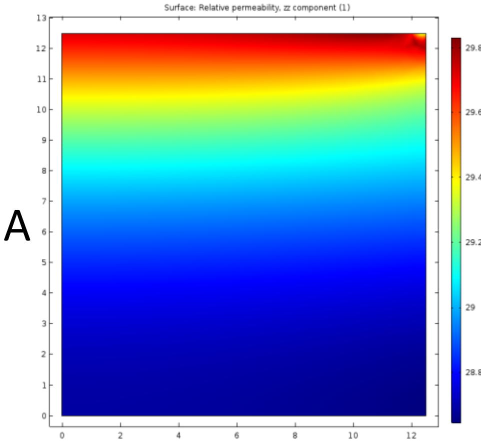
Suggested geometry for the 1” sample size

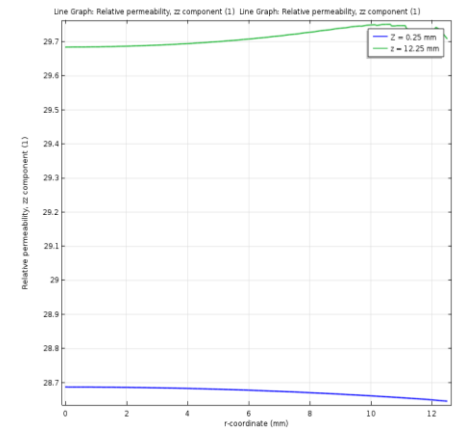


30 A

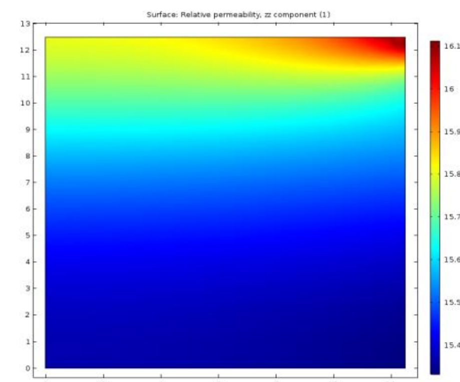


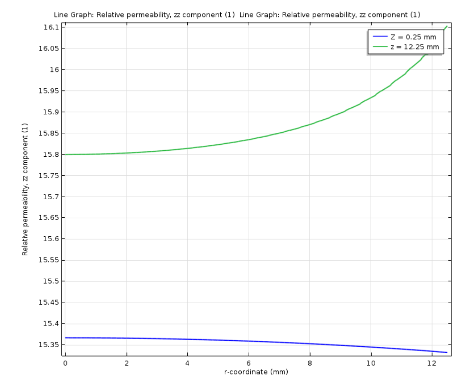
1 A





2 A





Maximum flux density in the FR is ~ 3 kG, which is within reach of ferrite materials. → Consider ferrite as a material of the FR.

MN100 is a good candidate

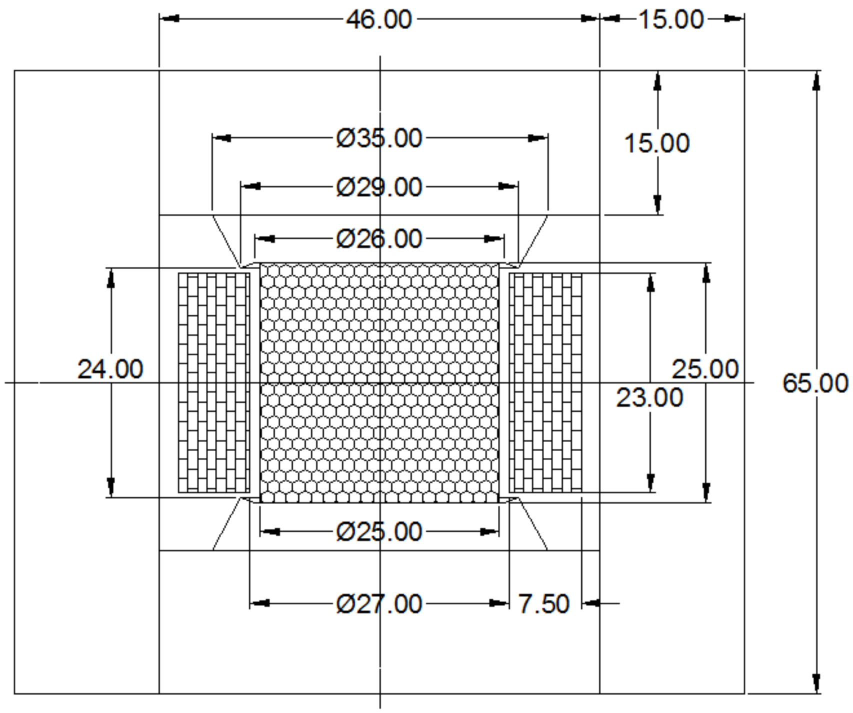
Initial permeability	9000
Saturation density	4700 G
Coercive force	0.3 Oe

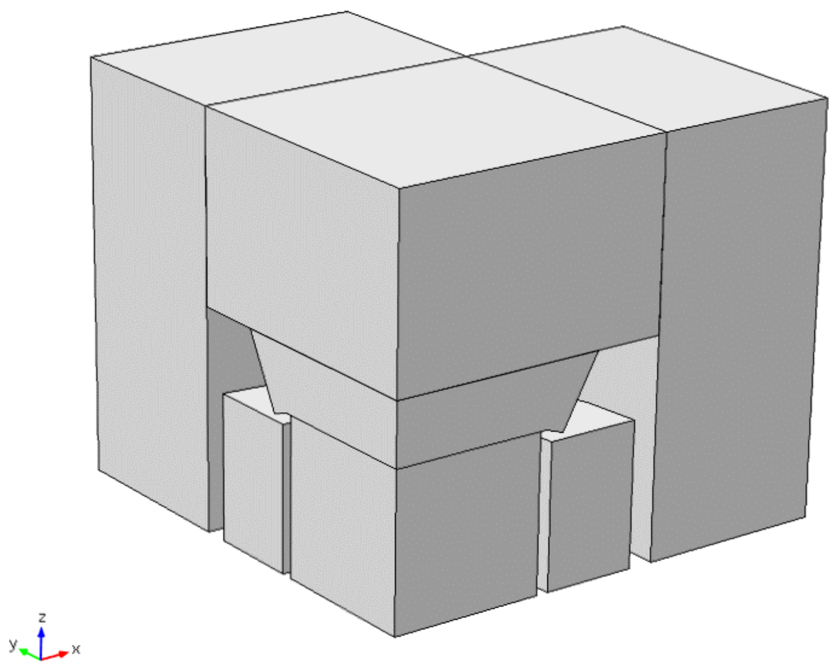
To gap or not to gap ?

At 2 A; $\mu = 9000$

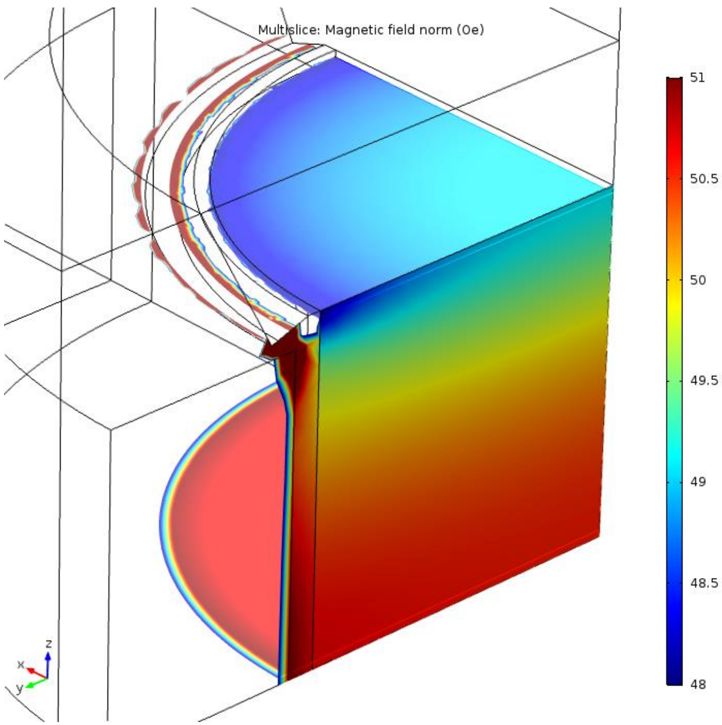
	With 0.1 mm gap	No gap
Average μ	17.35	15.52
Spread	33(top) – 17(bottom)	17.3(top) – 17.0 (bottom)
Magnetic resistance	12%	0.3%

Design Concept

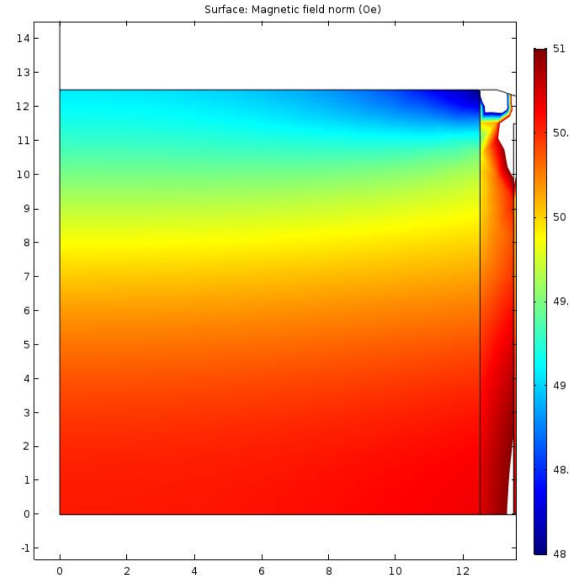




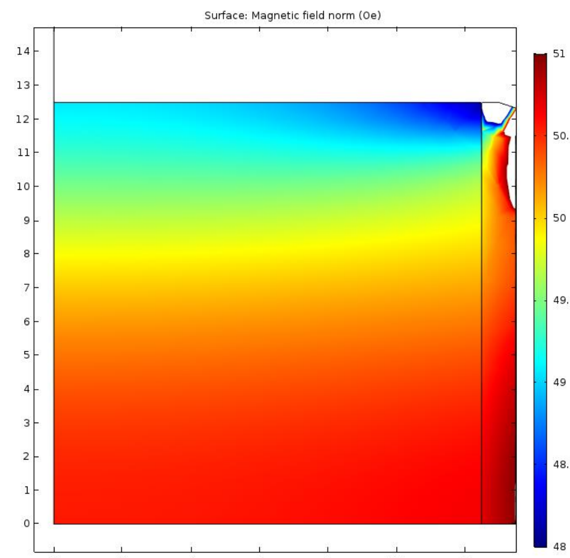
Field variations due to the absence of the axial symmetry



X plane



Diagonal plane



Excitation and Signal Coils

Excitation Coil

Coil cross-section is 7.5 x 23 mm^2.

Rectangular copper wire: 0.039” x 0.124” bare or 0.050” x 0.136” insulated

→ 4.4 mm^2 per one turn.

If 80% of the winding density , 5.5 mm^2 per turn and totally 30 turns in the coil.

Thicker coil must be made to keep the maximum current checked.

Coil cross-section must be 12.5 x 23 → 50 turns and the maximum current 50 A.

The coil can be made. We still can play with dimensions.

Signal Coil

Expected voltage when the current increases from 15 A to 16 A→ $\Delta I = 1$ A.

$\Delta\Phi$ = 1e-6 Wb

dI/dt = 1A/s

$U1 = d\Phi/dt = (\Delta\Phi/\Delta I)*dI/dt$ = 1e-6 V

If signal wire diameter is 0.1 mm, we can put 200 turns on the sample

Expected U = 0.2 mV. If 10 A/s, U = 2.0 mV.

To increase sensitivity, more turns can be wound.

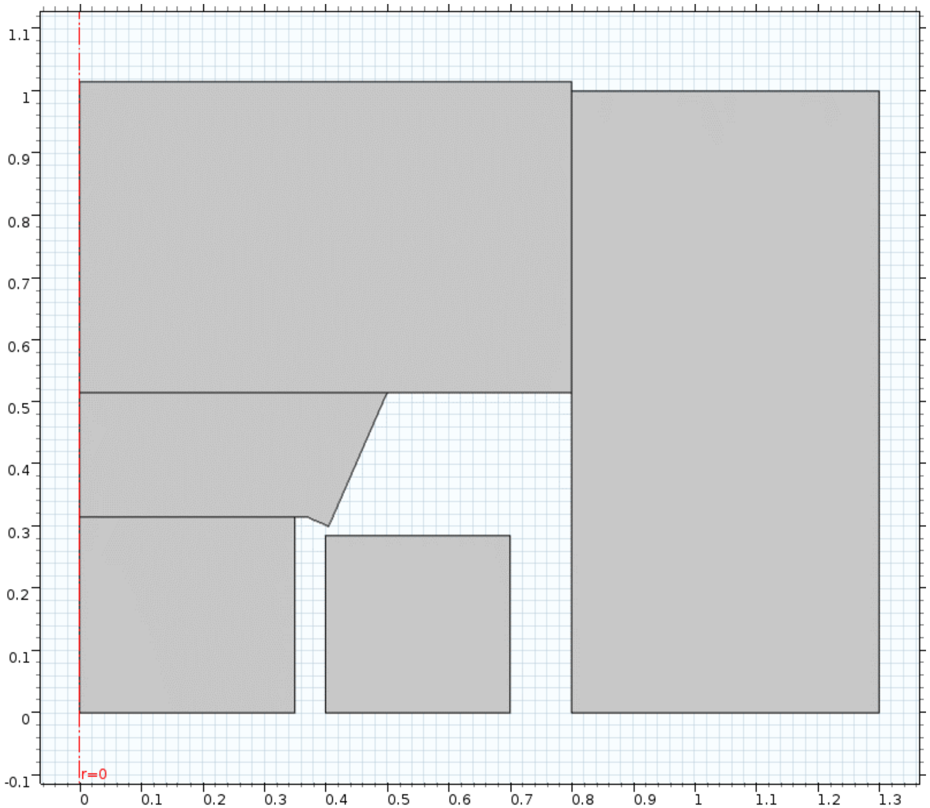
Corrections

1. Largest estimated Garnet sample possible to be drilled out from cut off triangular pieces: diameter 0.70” with 0.80” thickness.
2. MN-60: Your sizes are feasible.
3. We work on inches.

To Do List

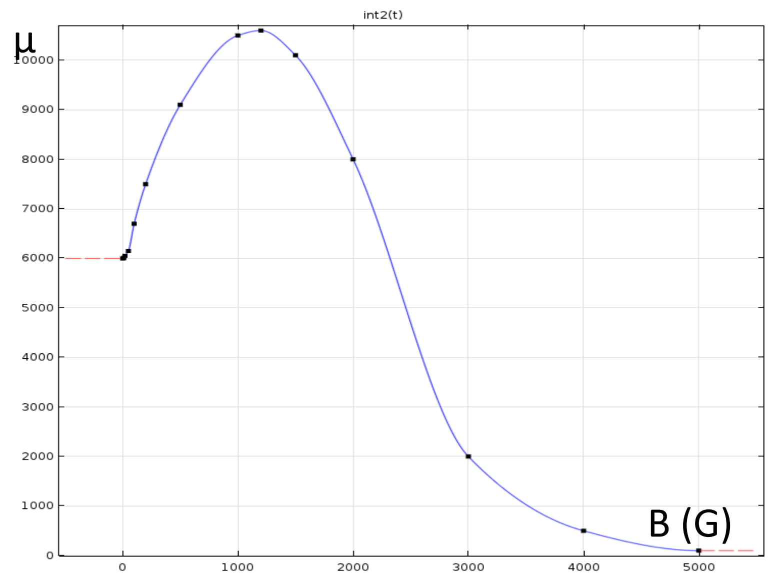
1. Scale the magnet design to the allowed size of the sample.
2. Use fractional unit system to avoid any uncertainties
3. Use MN-60 material for magnet system optimization

Updated Geometry – 2D



Sample size: Ø 0.7", h = 0.57" (16 mm)

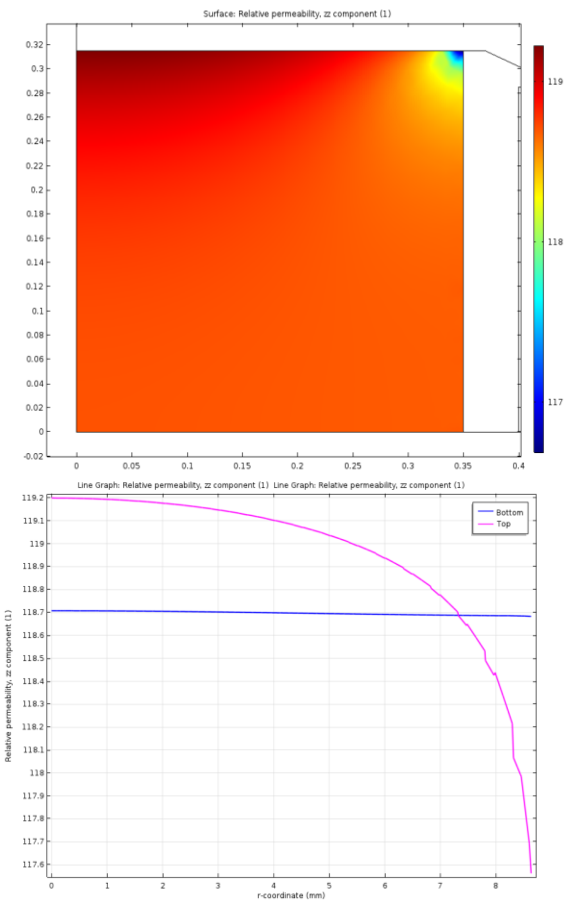
MN60 material magnetization curve

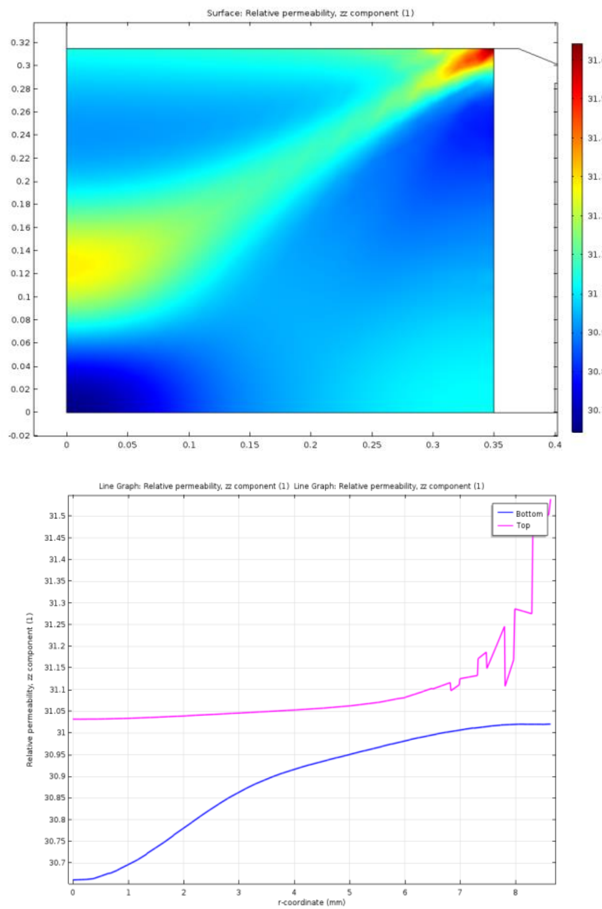


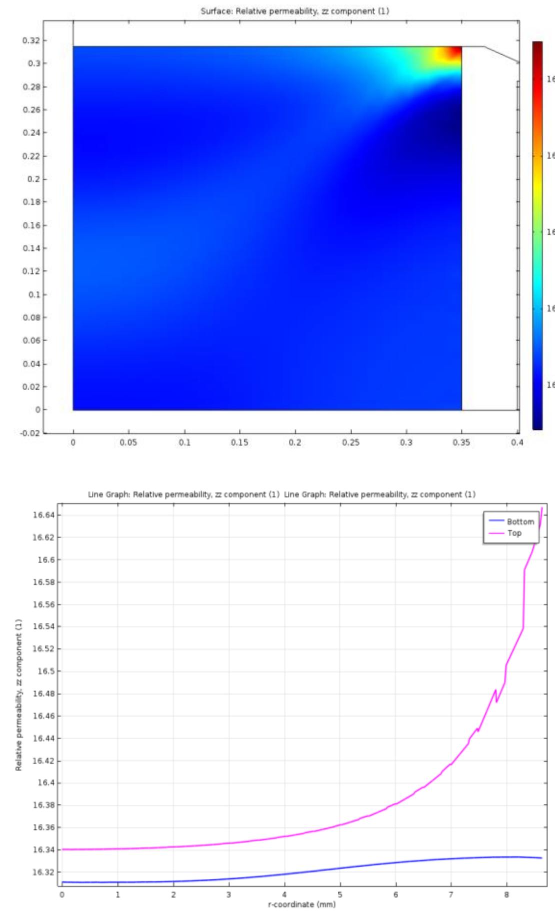
Coil width is 0.3" and the height is 0.57" → S = 110 mm^2
Total amount of ampere-turns is 30 x 30 A = 900 A
This gives the engineering current density of ~8 A/mm^2.
To limit the real current density to the 10 A/mm^2 level,
we need to have the winding density of ~0.8 →
rectangular wire must be used.

Rectangular copper wire **gauge 14**;
Bare copper cross-section is 2.5 mm^2.
Heavy build film insulated → side is 0.07" = 1.78 mm
The number of turns in one row N1 = 0.57/0.07 = 8
Number of layers in the coil NL = 0.3/0.07 = 4
This gives the total number of turns 32
→ **30 turns** can fit the cross-section.
Length of wire is 32 x pi x 1.1" ~ 3 m (10 ft)
Expected wire resistance is ~20 mOhm;
At 30 A the power is 18 W.

I = 0.2 A	I = 1 A	I = 2 A

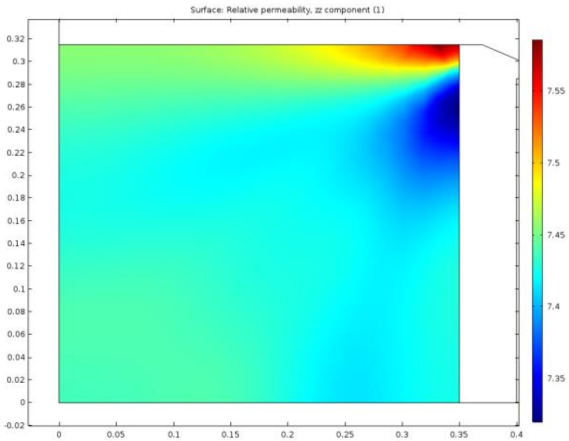


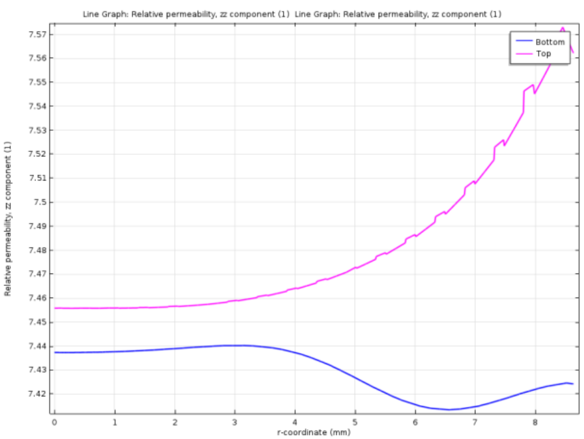




I = 0.2 A	I = 1 A	I = 2 A
Average μ = 118.5	Average μ = 30.9	Average μ = 16.4
Spread ~3.0%	Spread ~3.3%	Spread ~3.0%

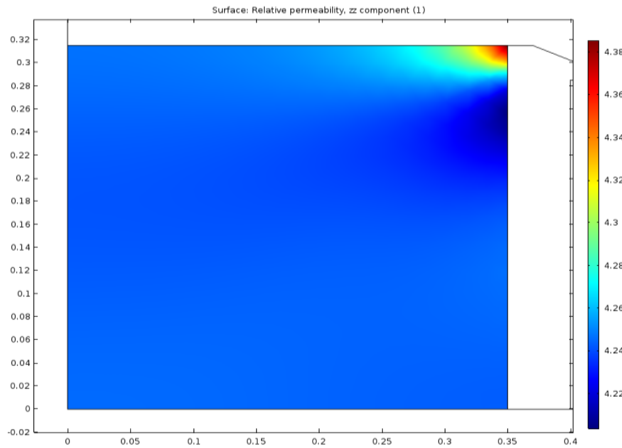
I = 5 A

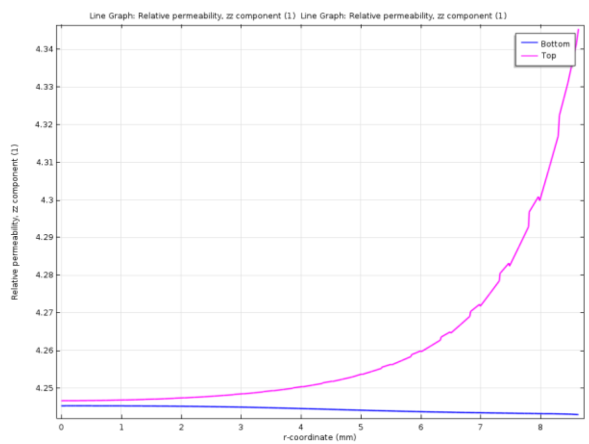




Average μ = 7.4
Spread ~3.5%

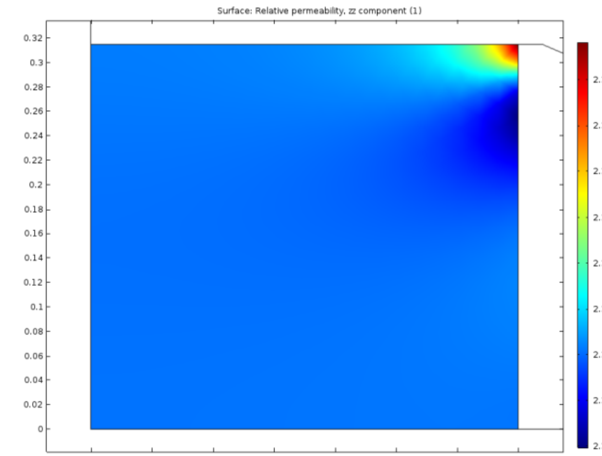
I = 10 A

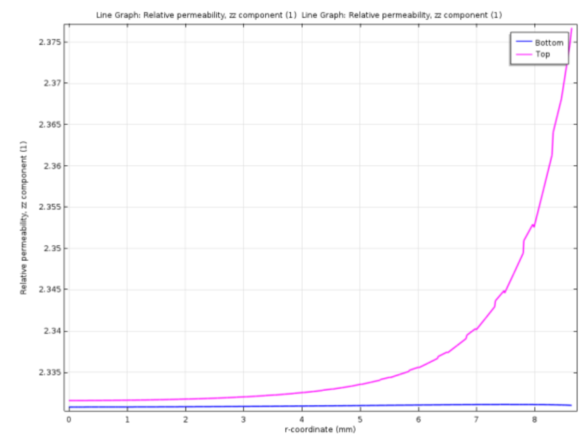




Average μ = 4.2
Spread ~4%

I = 25 A



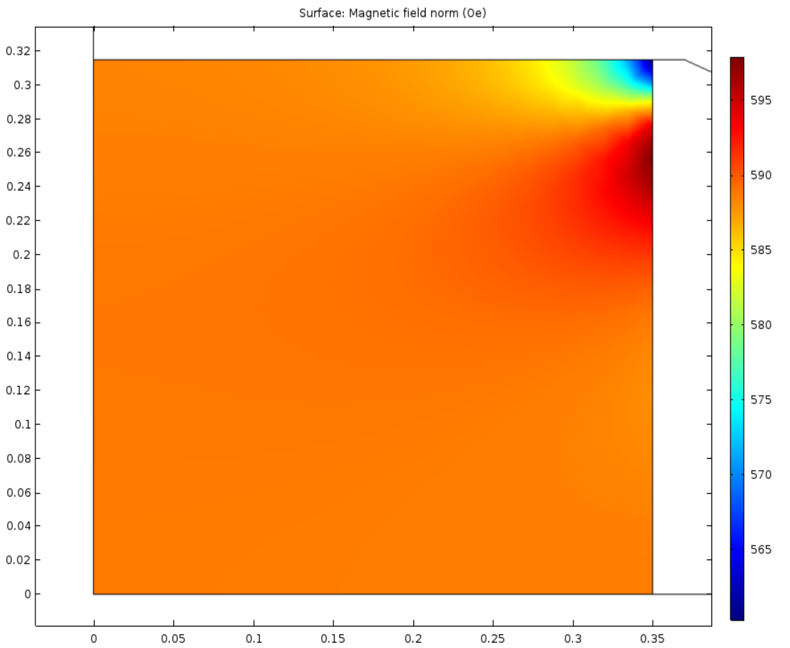


Average μ = 2.33
Spread ~3.8%

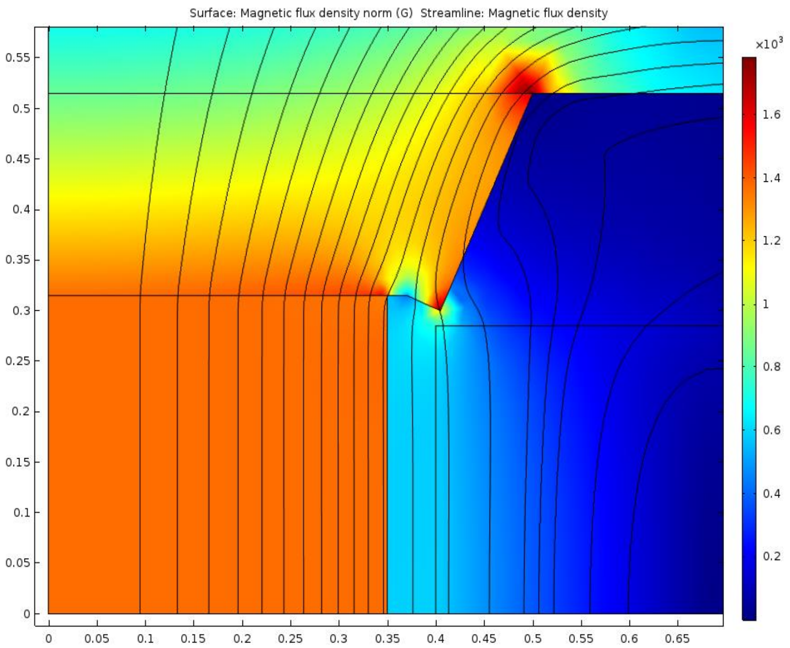
Flux return material saturation check-up

I = 25 A

Magnetic field in the sample is ~600 Oe

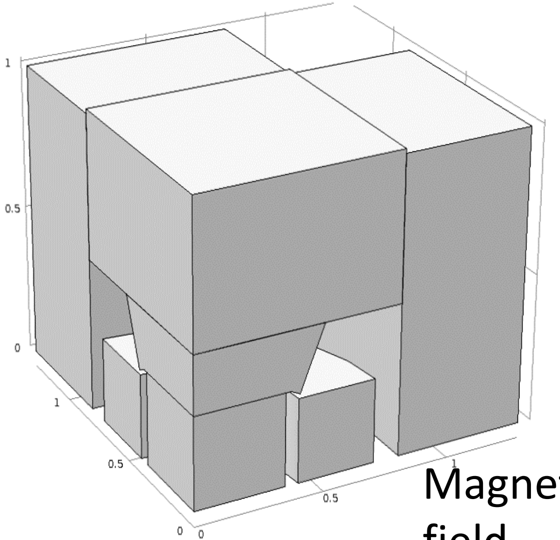


Flux density in the sample is ~1400 G



No saturation is expected in the FR

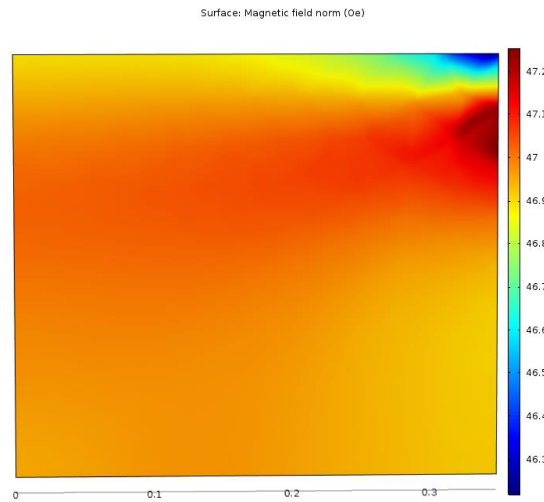
3D verification at 2 A

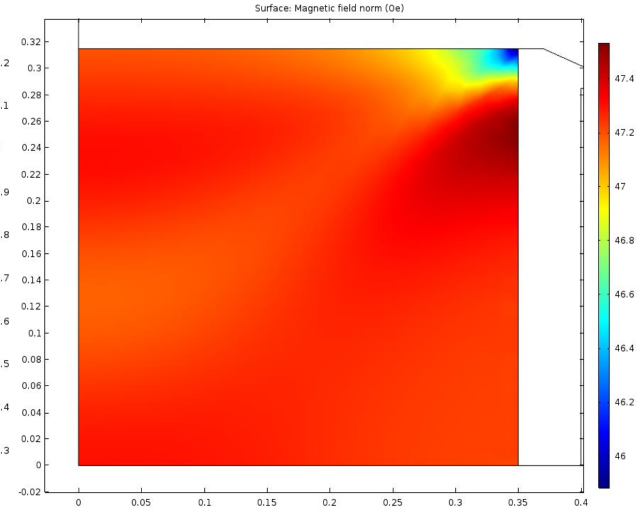


3D

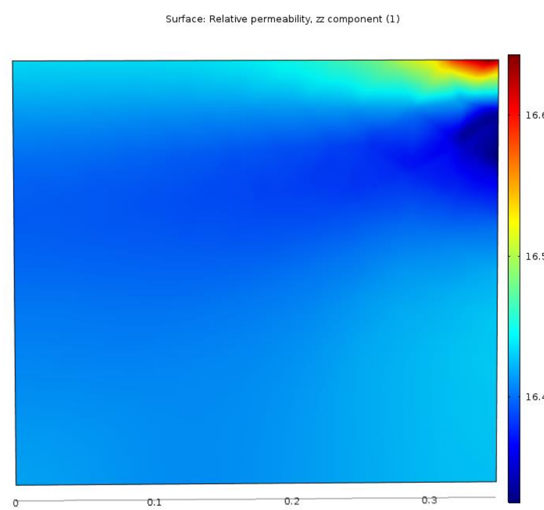
2D

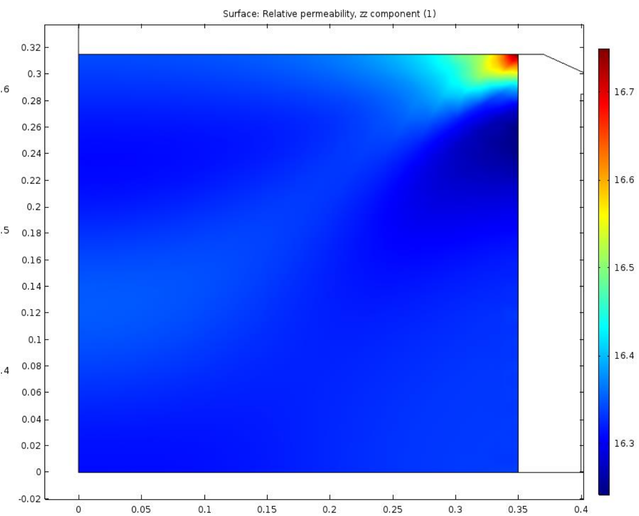
Magnetic field





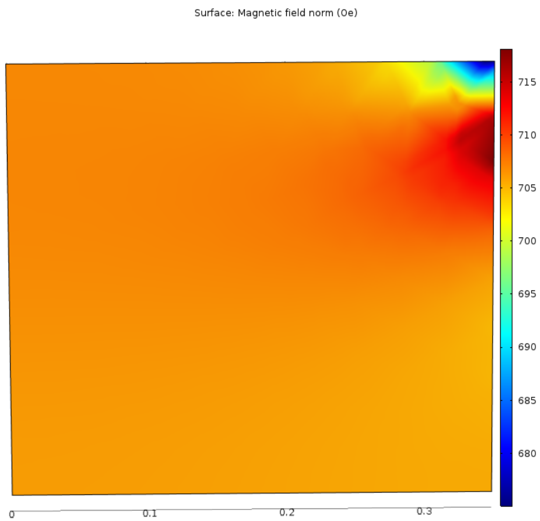
Permeability

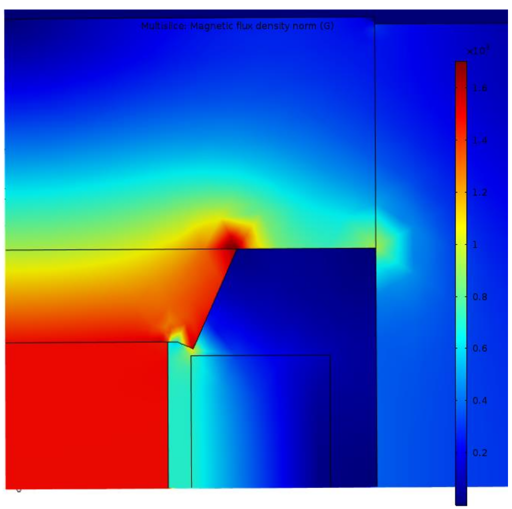




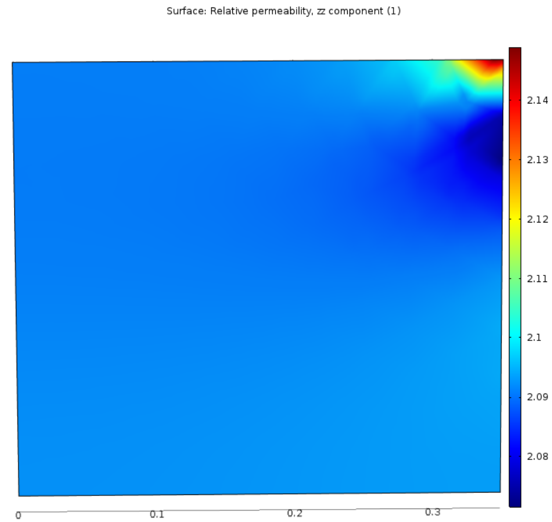
3D results at 30 A

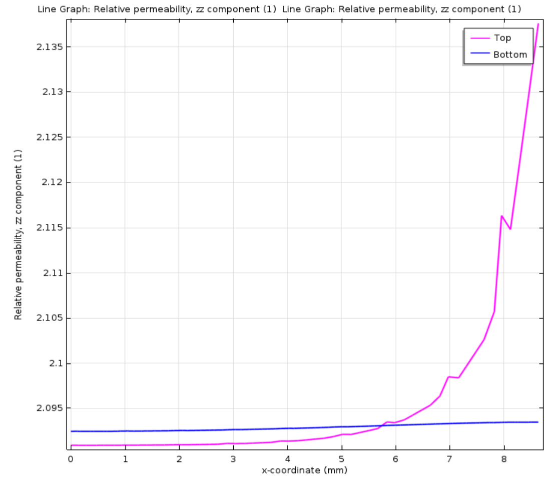
Magnetic Field





Permeability





Maximum magnetic field in the sample is ~700 Oe;
Maximum flux density in the FR is ~1700 G