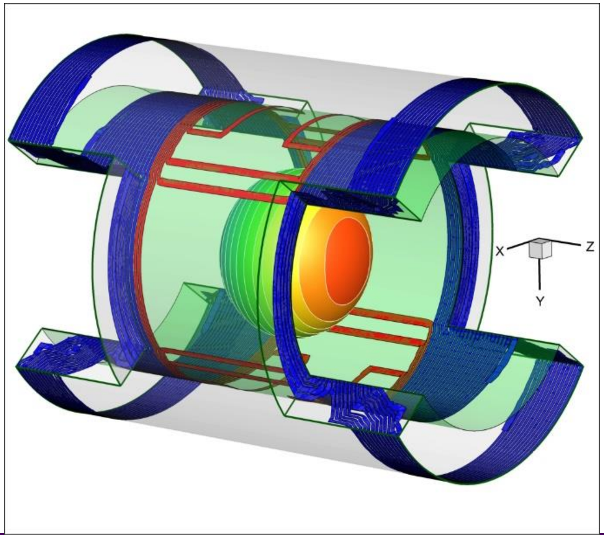
A 3T Head Scanner Designing Stage: the HTS magnet and the 200mT/m Hyper-Vision Gradient Coil

Kyoto Future Medical Instruments

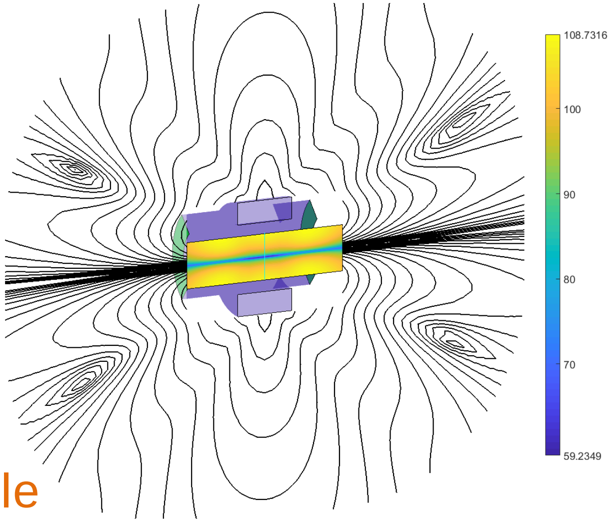
e-poster presentation #: Engineering Beyond RF Coils . Day/. Date: Tuesday, 19 June 2018.
Session Time: 17:15

Abstract

This work presents the design stage of a 3T MRI head scanner aimed to register temporal physiological events in the scale below 1 sec while imaging brain structures below 0.5 mm of resolution. The hyper-vision gradient coil concept is capable to produce 200 mT/m and nearly 1900 T/m/s using a high end amplifier. The 3D folded coil exhibits shoulder cut of an aperture of 250 mm and a DSV of 250mmx210mm while keeping resistance, eddy currents, force and inductive decoupling with the HTS magnet under control. Details and characteristics of the coil and magnet are presented in this work.



Z-Coil



Sound field profile

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Introduction

- The causes of neurodegenerative diseases such as Alzheimer, Parkinson and dementia reminds unknown due to the lack of imaging tools capable to probe the interaction mechanism and interface of micro vessels with the brain tissue at the mesoscopic scale (<0.5mm).

- Current gradient coils performance limits the frontier of understanding of such mechanism mainly due to the lack of spatiotemporal resolution to probe physiological events in the scale below 1 sec and registering anatomical imaging with a resolution below 0.5mm.

- The connectome whole body gradient coil boosts 300 mT/m with risk of PNS if the coil is used at full performance.

- In this work an alternative head symmetric gradient coil is architected to produce 200 mT/m and nearly 1900 T/m/s to delve at the scale below 0.5mm. The coil will be combined with a 3T HTS magnet.

The Magnet

- Bo strength 3T. HTS DI-BSCCO Type-HT (wire characteristics was provided by Sumitomo Electric Industries, Ltd.)
- pk-pk homogeneity smaller than 5 ppm was targeted in a 240 mm DSV
- The number of axial turns in each coil were constrained to be even, the peak field and the Br field component were constrained.
- safety margin, axial force, simplified hoop stress, sensitivity of the solution and computing precision were also controlled to guarantee a reliable and practical to manufacturer design.
- Bare bore size 600 mm was required.
- All coils at same inner radius.
- Stored Energy < 2.9MJ
- |Br|<4 T
- Peak Field < 5 T

Stability Analysis

- Aim: Determine minimal number of azimuthal shims rails and guarantee a post-passive shim homogeneity small than 5 ppm within 240 mm DSV

- Predict the post-manufacturing homogeneity and spherical harmonic strengths.

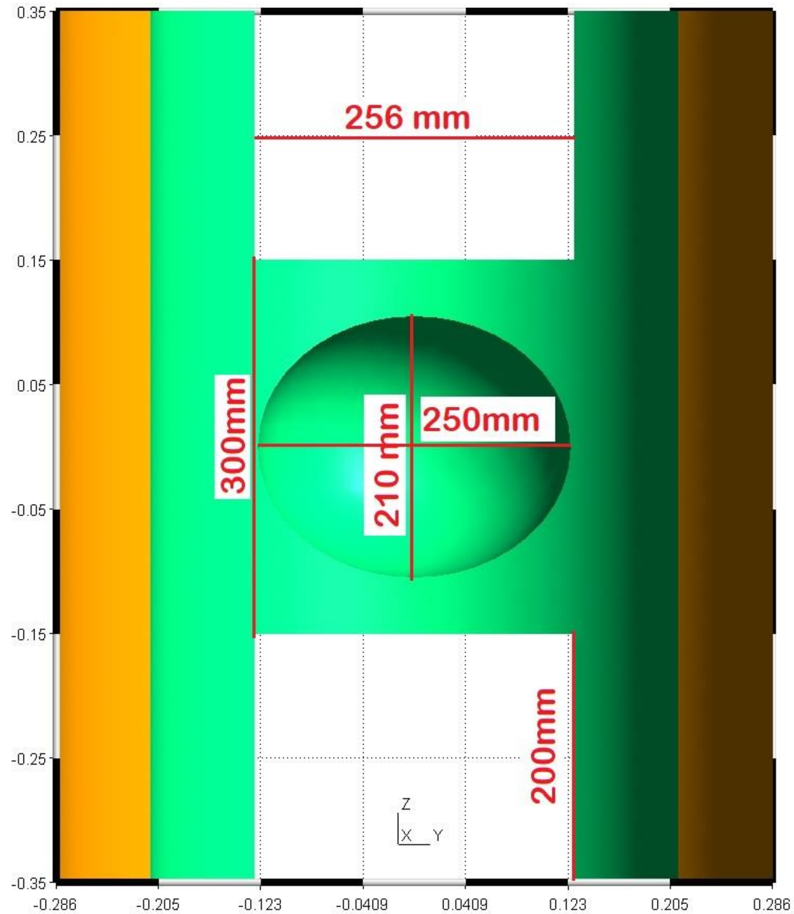
- All coils to be randomly perturbed in the axial and radial directions more than 10000 times from the initial design. The range of tolerance was ±0.5 mm.

- Minimize the numbers of pockets to use on regards of a probable post-manufacturing homogeneity.

- Predict the possible maximum thickness to design the shim rail radial thickness profile.

Hyper Vision Gradient Coil

- Design a symmetric Head two Gradient coils: ID 360mm and 400 mm. OD 590 mm.
- Gradient sensitivity > 200 µT/A
- Inductance <450 µH
- Open access to shoulder 250 mm
- Field linearity better than 6.5%
- Force/Torque balanced.
- Minimum gap between consecutive conductors 1.7 mm
- Copper sheet thickness < 3 mm
- Active shims inductively decoupled with magnet.
- Peak current density minimized in Cryo.
- Cryostat force balancing. Modal coil.



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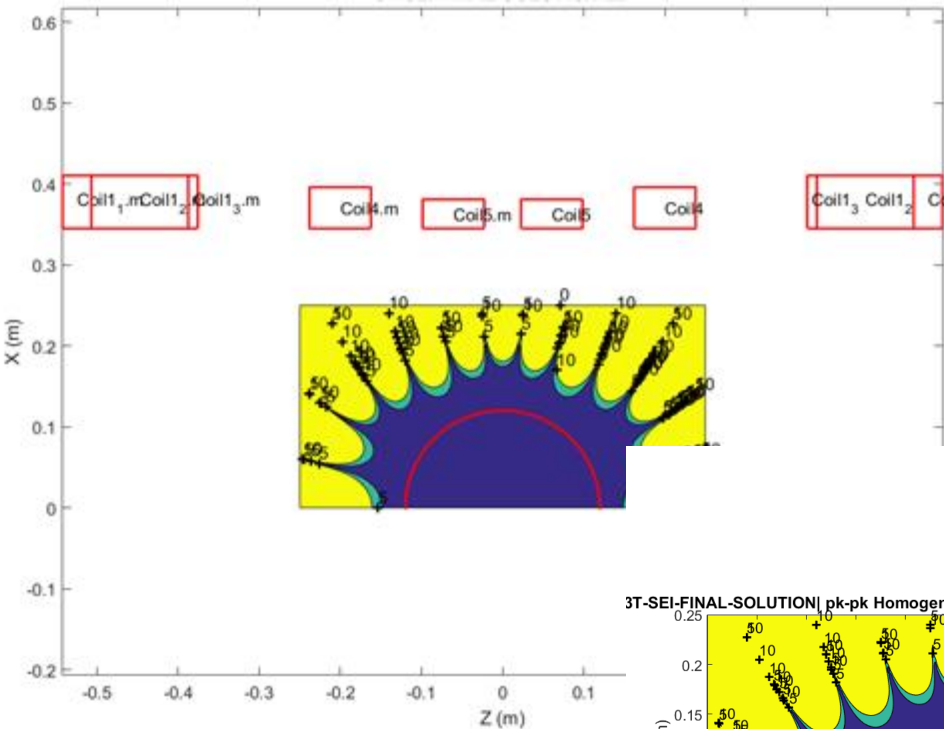
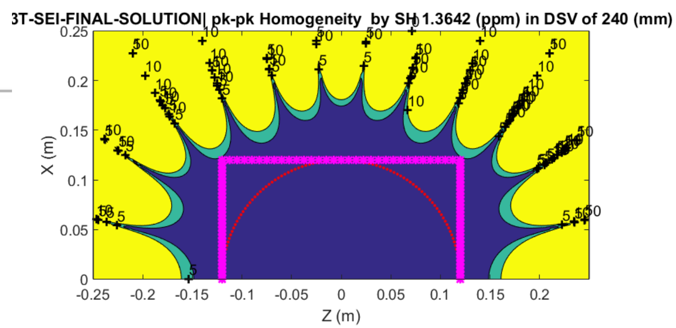
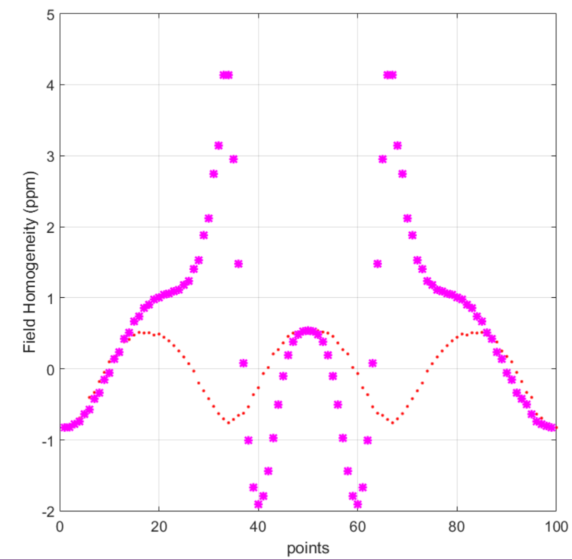
Magnet Design



- Stored energy:2.6MJ. Peak Field:4.96T.
- Peak Br field:3.76T
- Safety margin 80%.
- Pk-pk homogeneity 1.36 ppm, 240mm dSV





- Bo 3T

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EM Design Stability

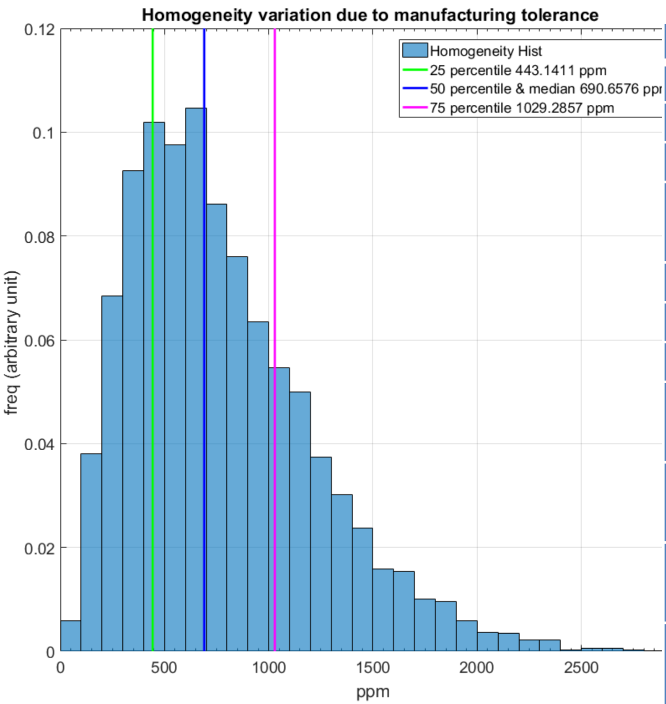


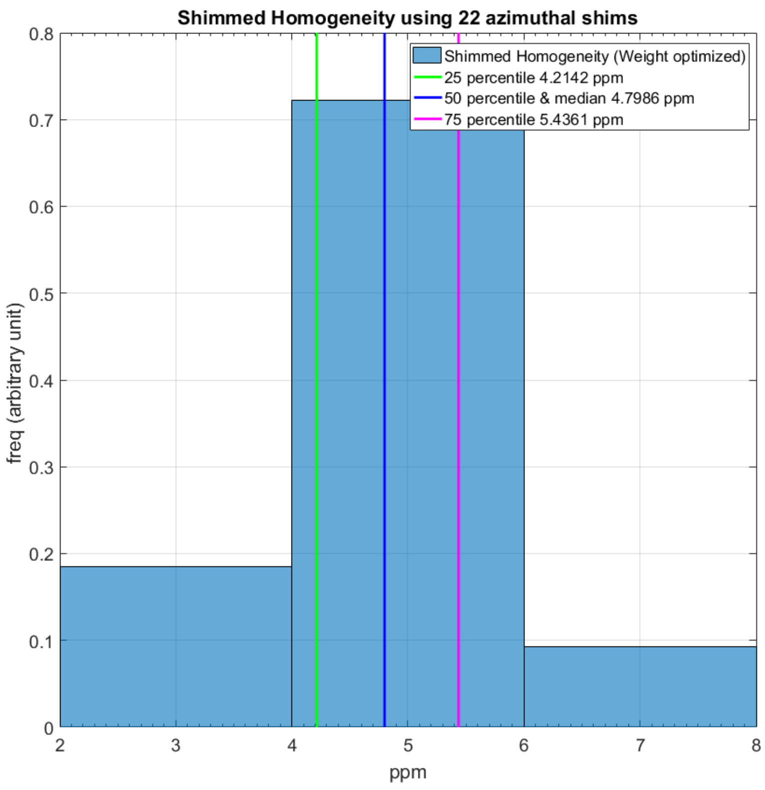
Table 1. Statistical Analysis

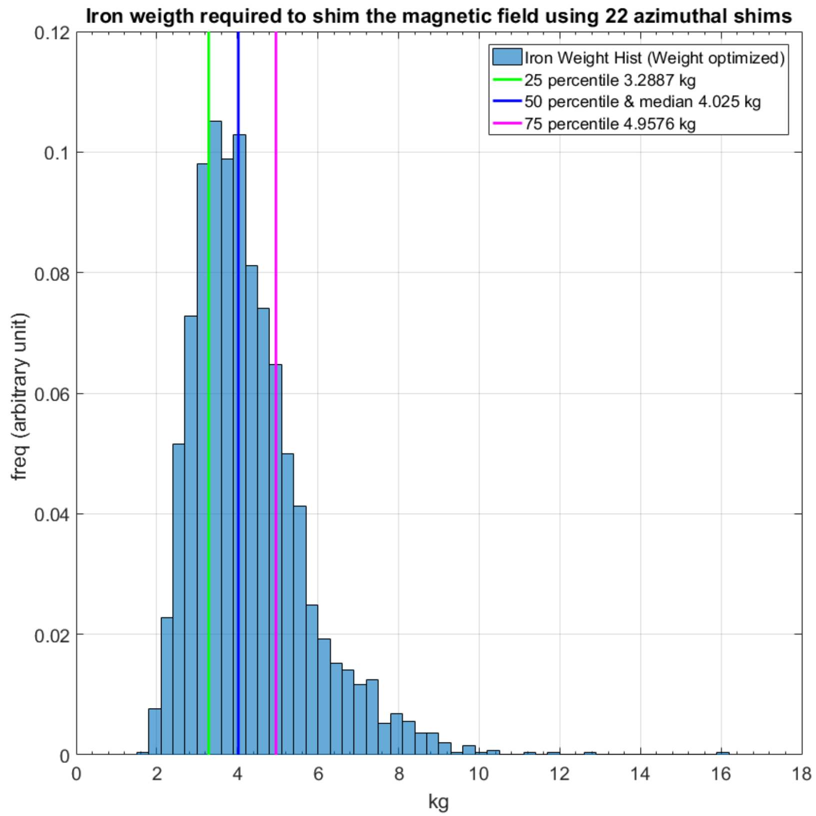
Parameter	Value	Unit	Notes
Mean	774.33	ppm	Central Tendency of the Distribution
Median	690.65	ppm	
Standard Deviation	437.58	ppm	Data Spread Behaviour
Minimum	17.84	ppm	
Maximum	2999.85	ppm	
Outliers	61		
25th Percentile	443.14	ppm	Quartiles
50th Percentile	690.65	ppm	
75th Percentile	1029.28	ppm	
Semi Interquartile Deviation	293.07	ppm	
IQ range	586.144	ppm	

Remarks

- **The main tendency is to produce 690.65 ppm after the magnet is constructed.**
- **The large group of in-homogeneities reside between the 25th and 75th quartiles.**
- **There is a range of 586.14 ppm between the quartiles.**

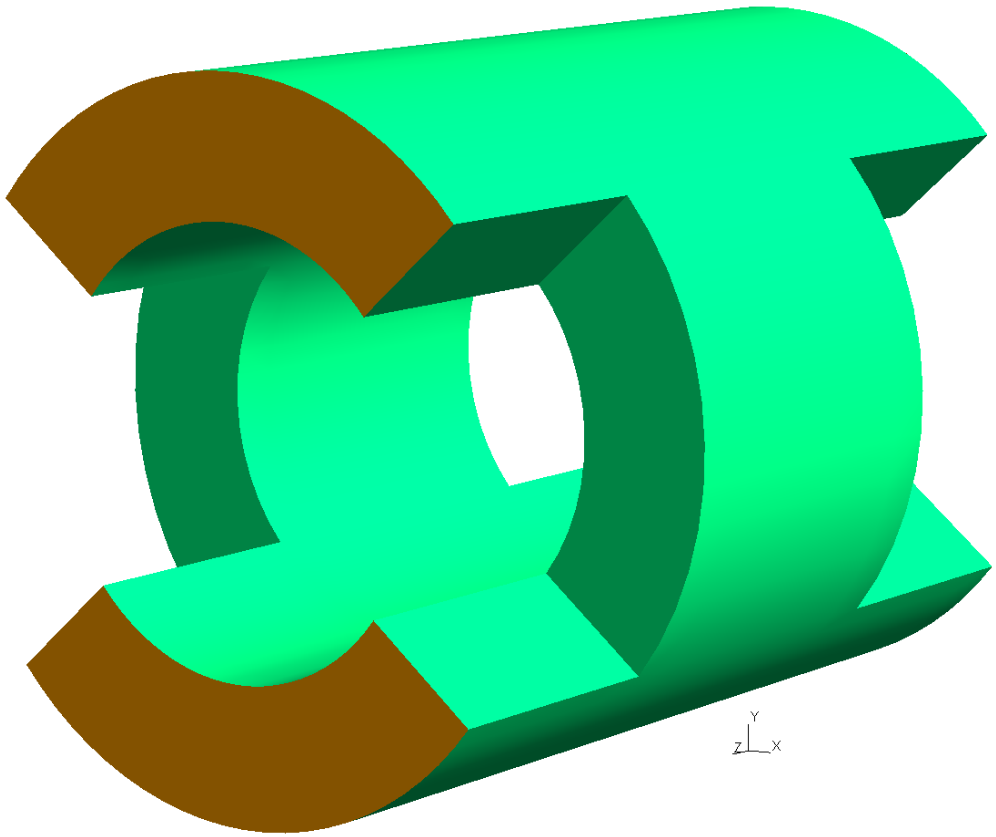
EM Design Stability

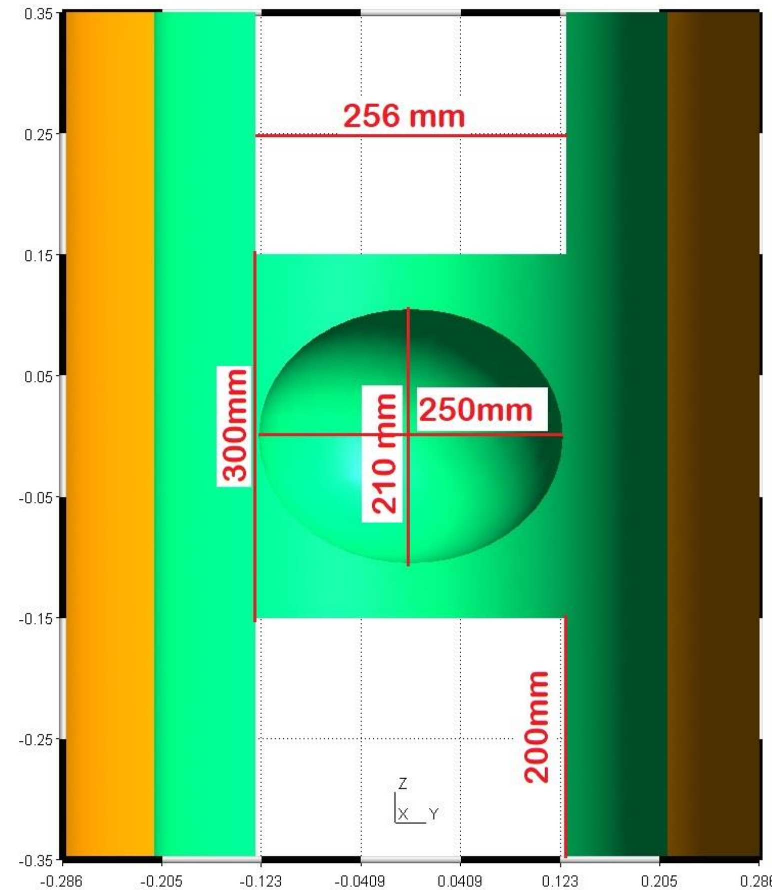




22 azimuthal shims and 17 axial shims and the thickness is constrained to 4 mm in each pocket. Optimal number of shim rails 22. Guarantee 100% shimming.

Hyper Vision Gradient Coil





Two models were designed: 360 mm ID,400mm ID

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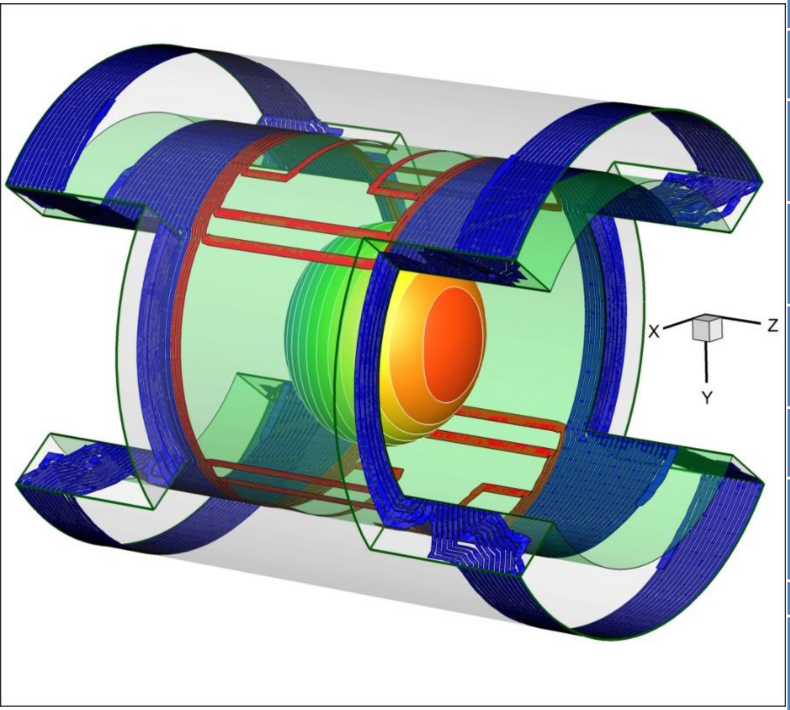
Hyper Vision Gradient Coil

Decouple from the Magnet



Z Coil Profile

Some characteristics of the Hyper-Vision gradient coils ("connectome")						
Envelope->	ID/OD-360mm/590mm			ID/OD-400mm/590mm		
Properties	X	Y	Z	X	Y	Z
η (μT/A)	258	257	250	203	204	251
Inductance (μH)	462	315	256	436	387	406
Resistance (mΩ)	97	119	84	91	118	120
Slew rate (T/m/s)@2000V	1078	1564	1893	894	1053	1245
Conduct. Thickness (mm)	2.2	2.5	2.2	2	2.5	3
Conduct. min width (mm)**	2.4	5	3.2	2.4	5	4.4
Residual Eddy (%)*	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Roll over from center (mm)	145	172	150	150	150	150
DSV	225mmX190mm			250mmX210mm		
Max Non-linearity (%)	6.5	6.2	-6.5	-6.5	-6.2	-6.5
Max Non-Uniformity (%)	-25	+28	-33	-23	+28	-27

*The linear term decays with only one time constant (one eigenmode excited). The eddy field in DSV max non-linearity is 5% respect to primary field for a long pulse of 1s

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Hyper Vision Gradient Coil

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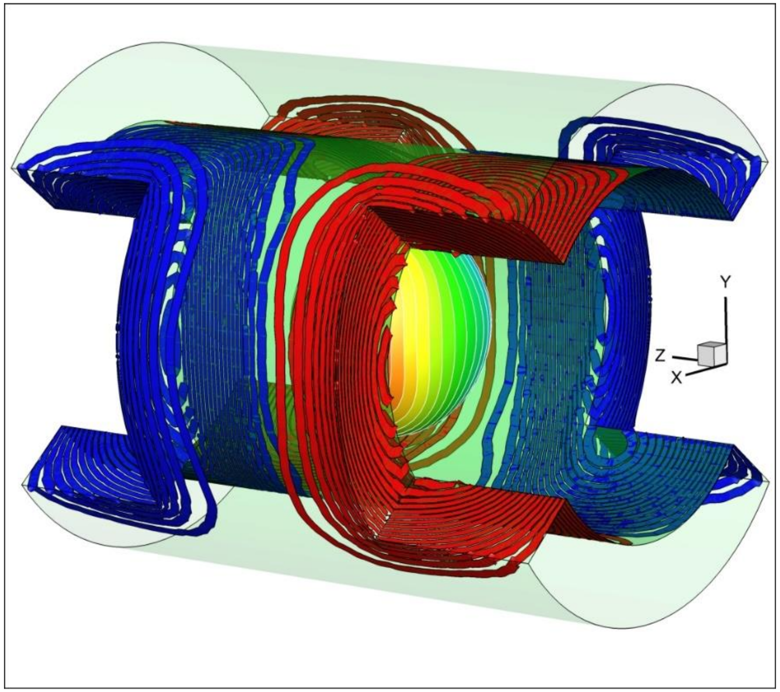

X Coil Profile

Some characteristics of the Hyper-Vision gradient coils ("connectome")						
Envelope->	ID/OD-360mm/590mm			ID/OD-400mm/590mm		
Properties	X	Y	Z	X	Y	Z
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Hyper Vision Gradient Coil

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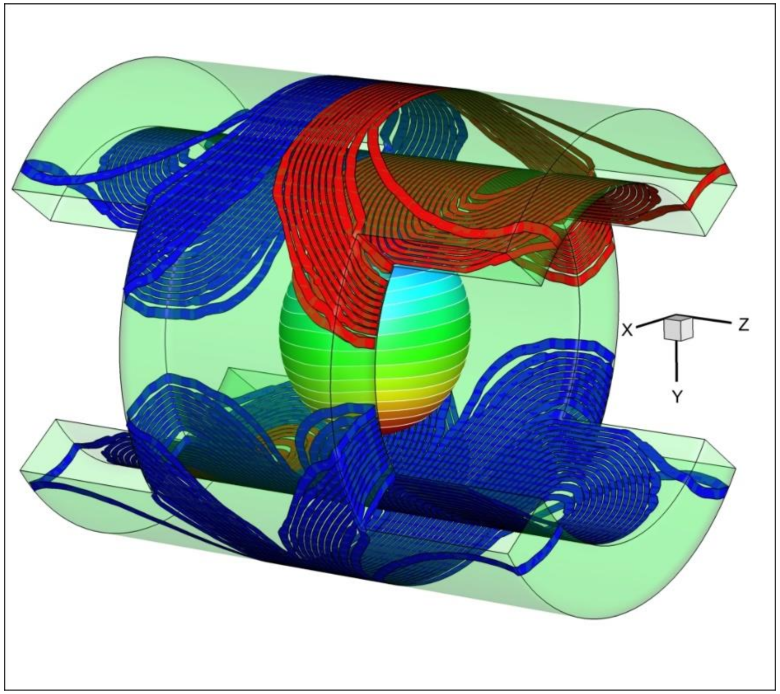

Y Coil Profile

Some characteristics of the Hyper-Vision gradient coils ("connectome")						
Envelope->	ID/OD-360mm/590mm			ID/OD-400mm/590mm		
Properties	X	Y	Z	X	Y	Z
η (μT/A)	258	257	250	203	204	251
Inductance (μH)	462	315	256	436	387	406
Resistance (mΩ)	97	119	84	91	118	120
Slew rate (T/m/s)@2000V	1078	1564	1893	894	1053	1245
Conduct. Thickness (mm)	2.2	2.5	2.2	2	2.5	3
Conduct. min width (mm)**	2.4	5	3.2	2.4	5	4.4
Residual Eddy (%)*	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Roll over from center (mm)	145	172	150	150	150	150
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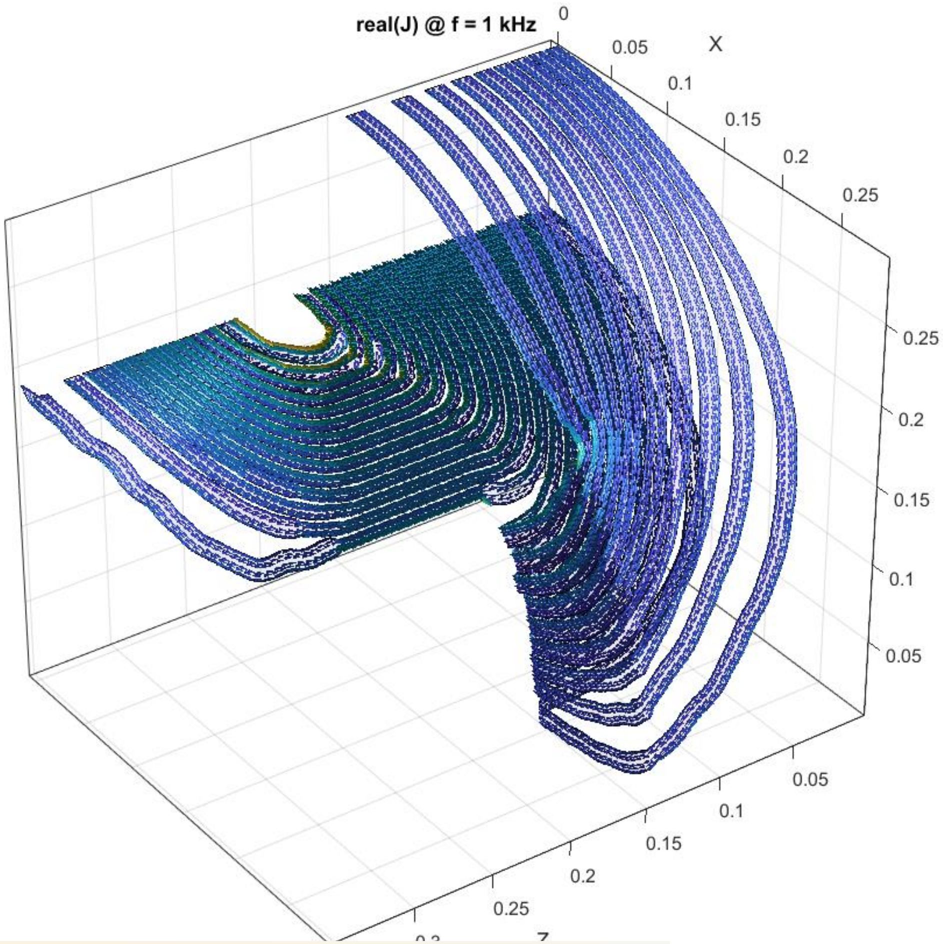
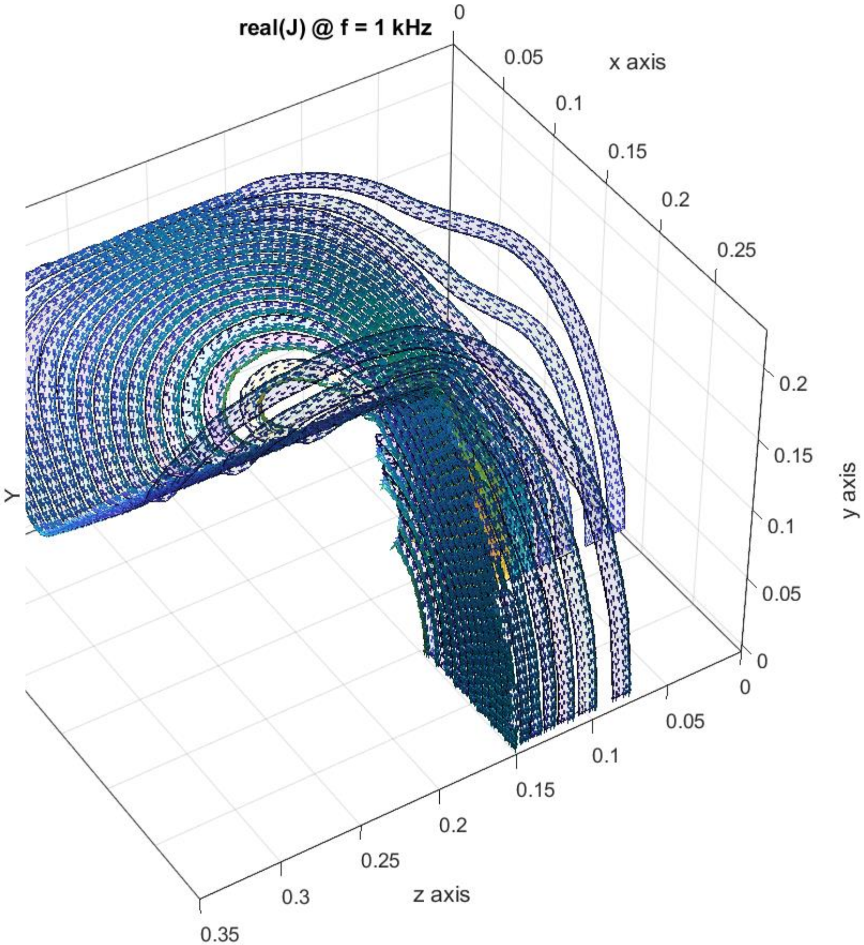
Hyper Vision Gradient Coil



Y Coil AC Model



X Coil AC Model

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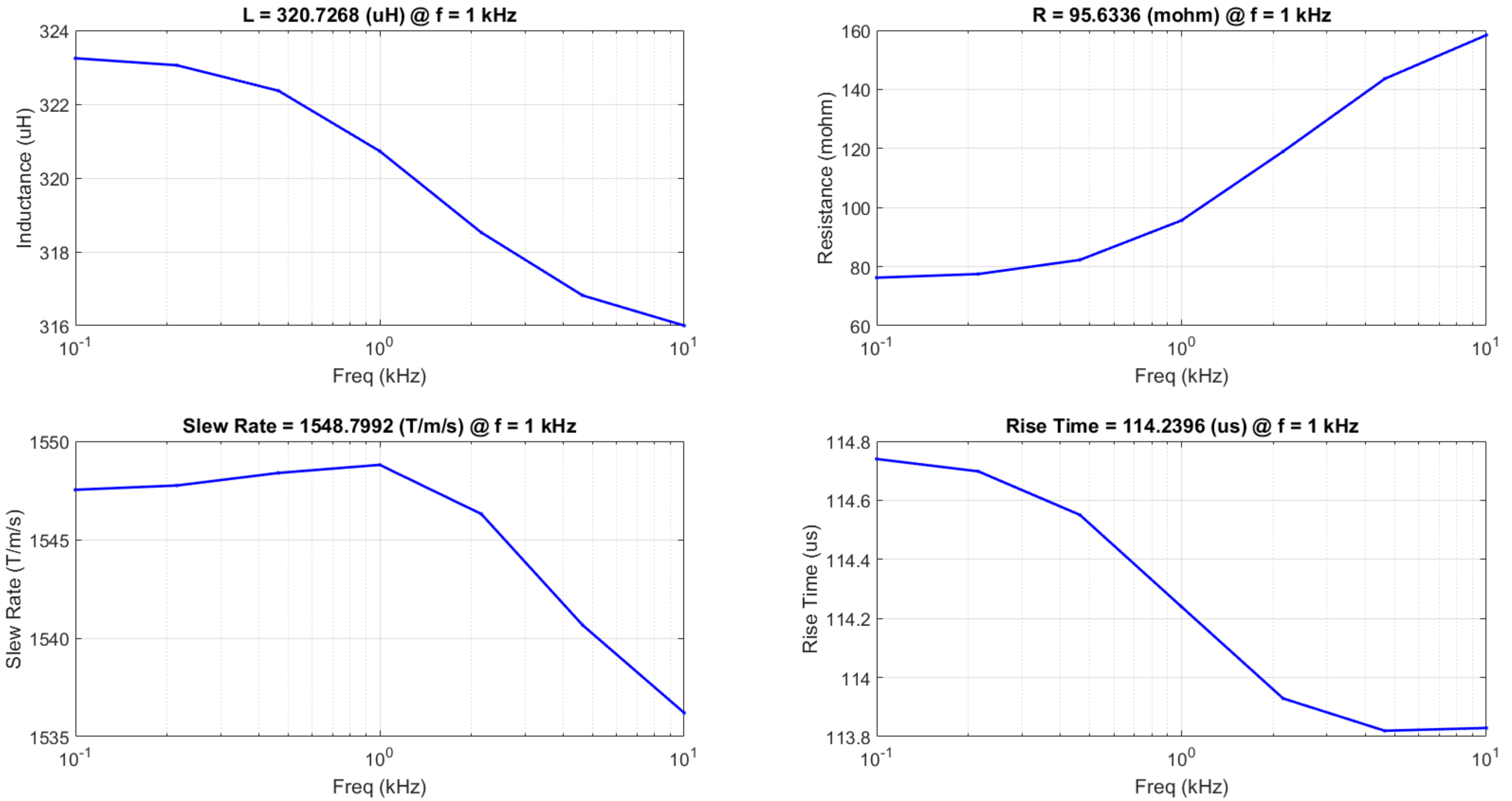
Hyper Vision Gradient Coil



Y Coil AC Model

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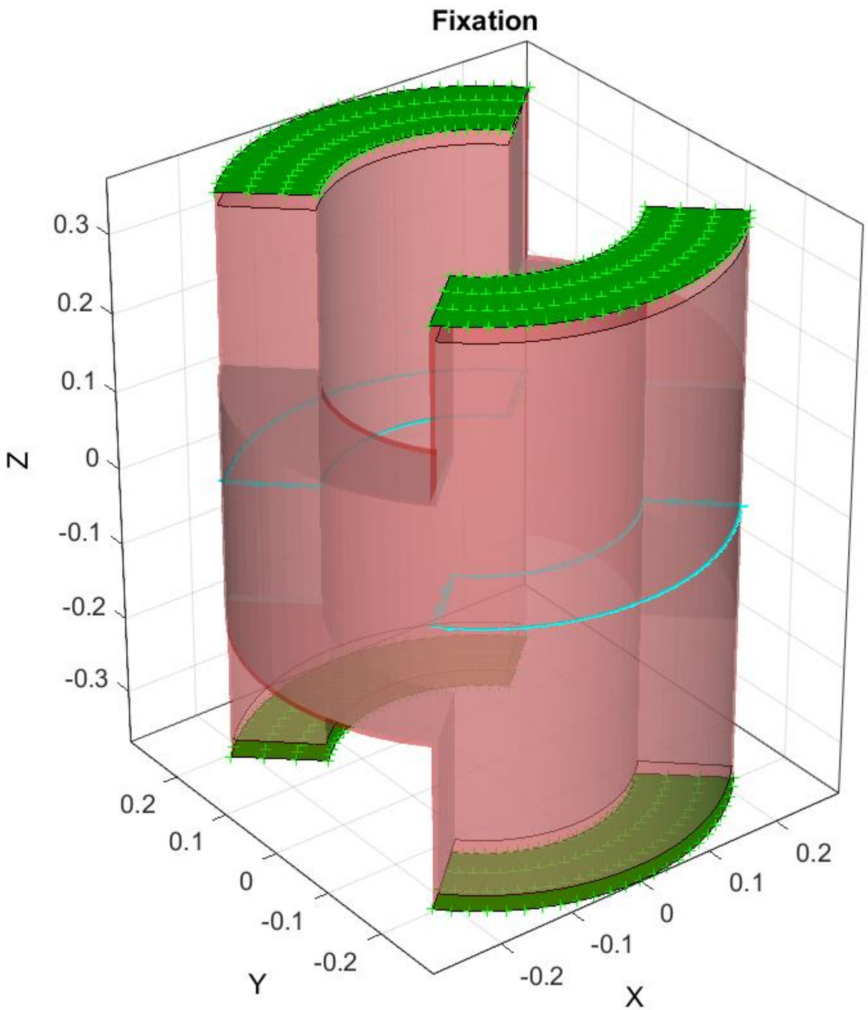
Hyper Vision Gradient Coil



Time-Harmonic 1 kHz

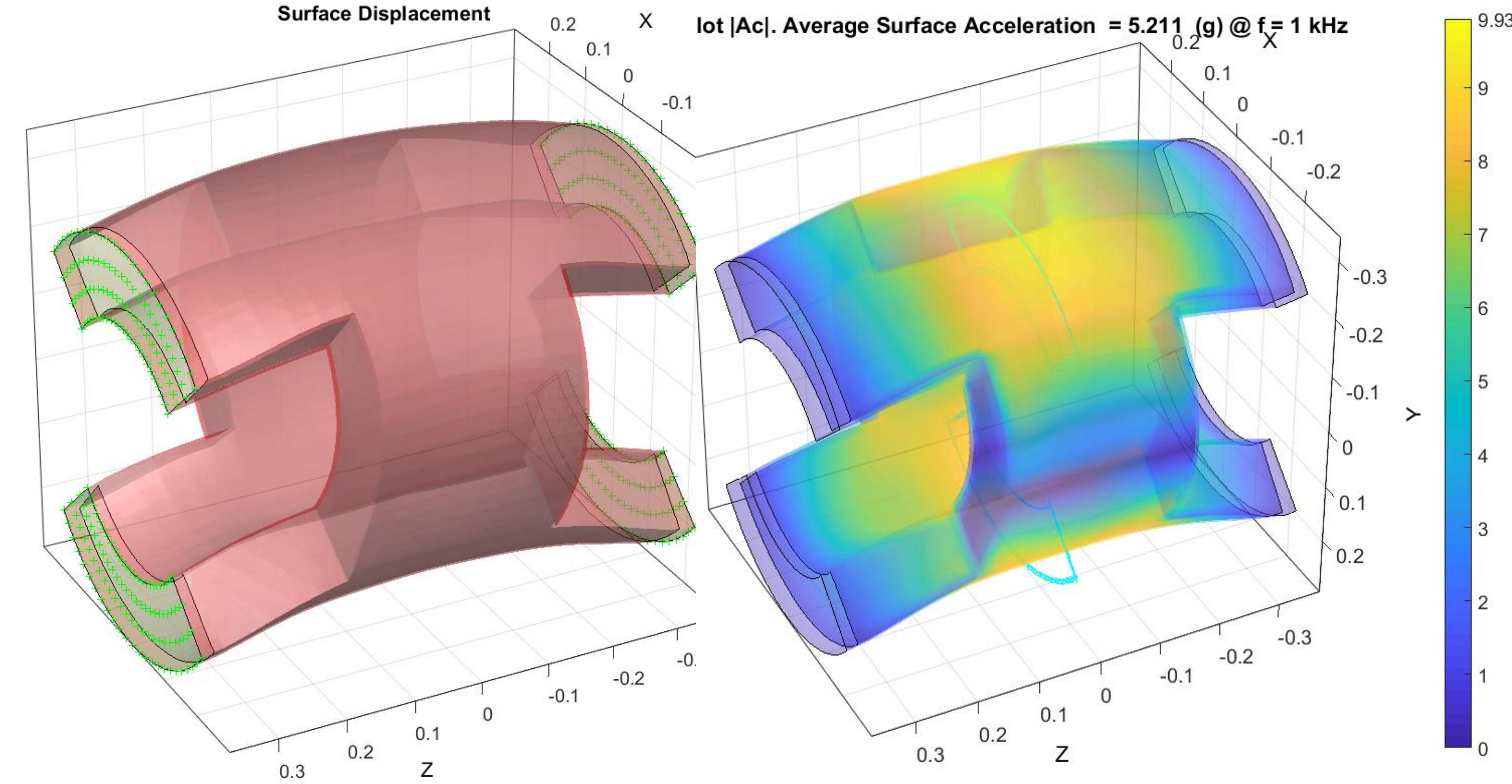
Typical epoxy and copper Young's module, poison ratio, density and damping.

Parameters to Calculate:

Displacement, velocity and acceleration and sound pressure.

Eddy current due to the term **v**x**B** and force.

Hyper Vision Gradient Coil-Y



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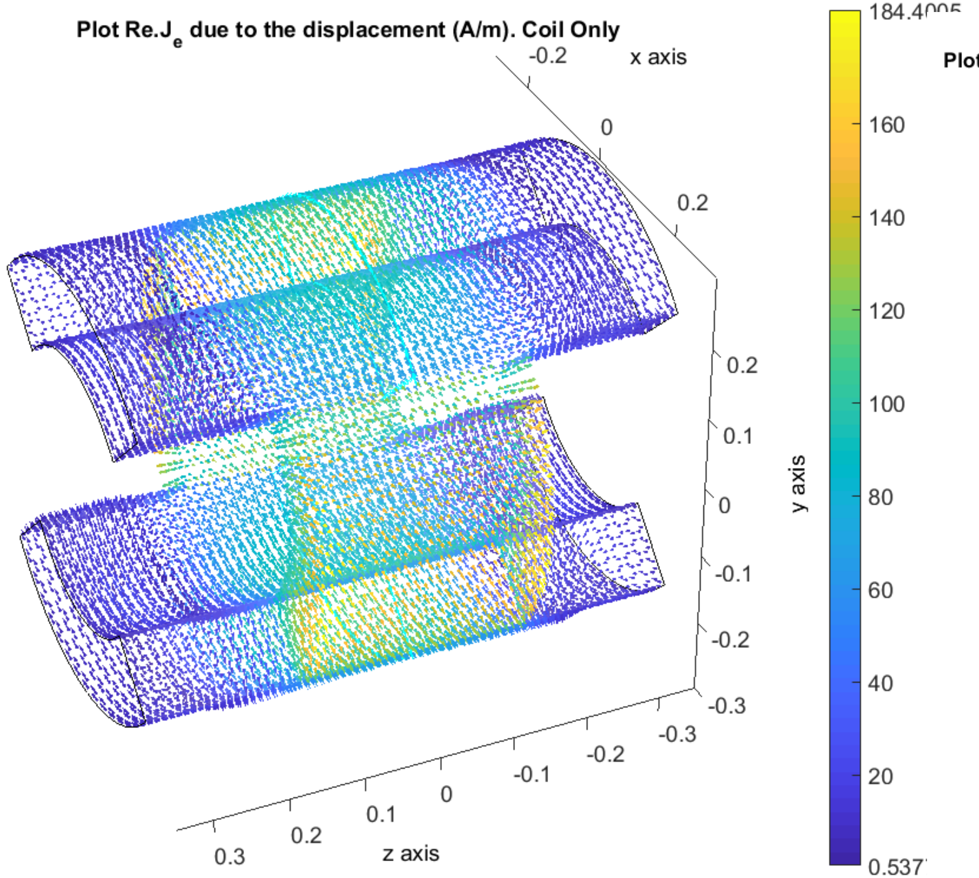
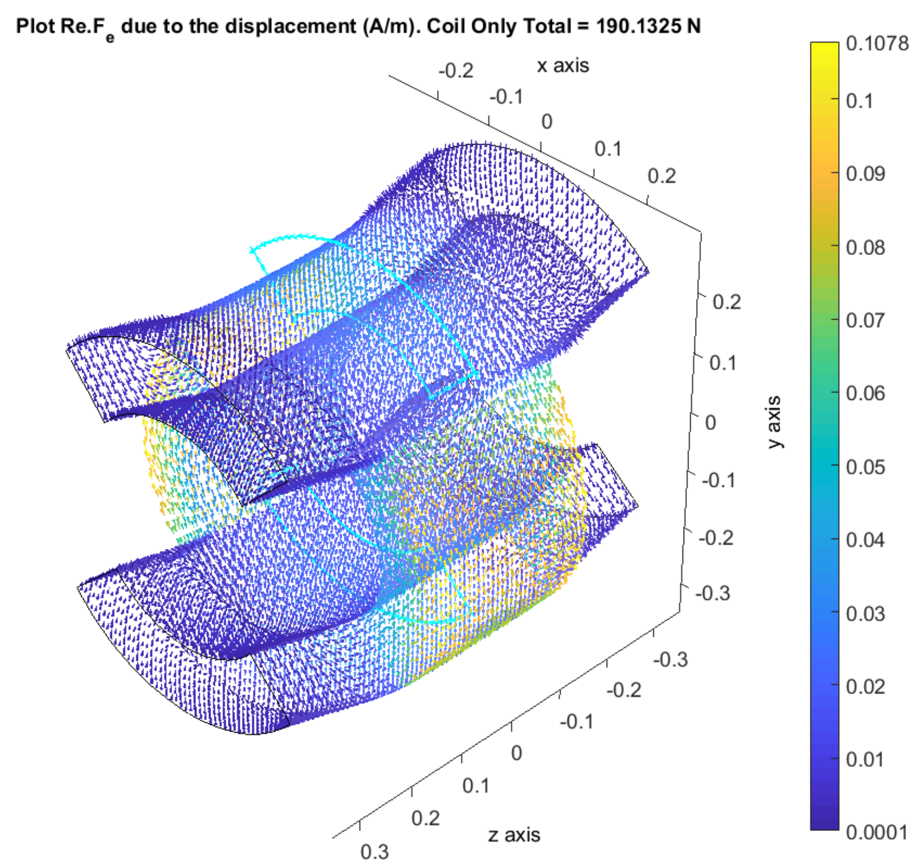
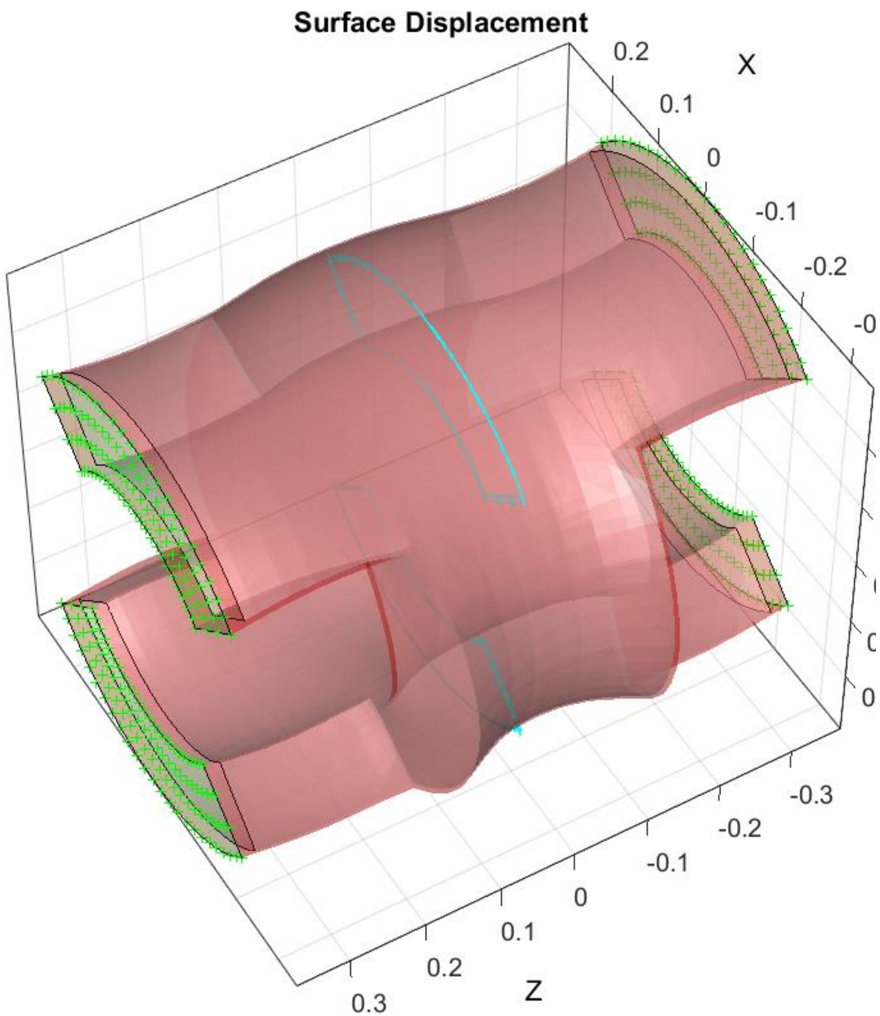
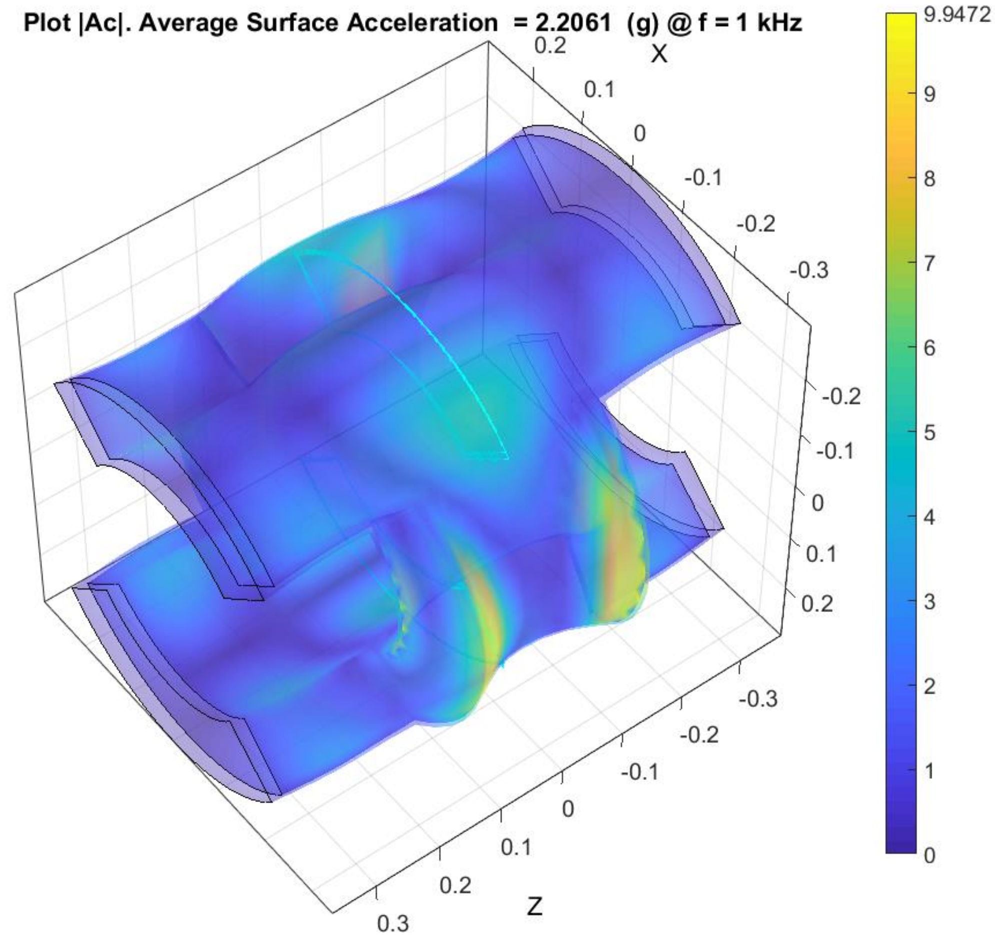
Hyper Vision Gradient Coil-Y





Hyper Vision Gradient Coil-X





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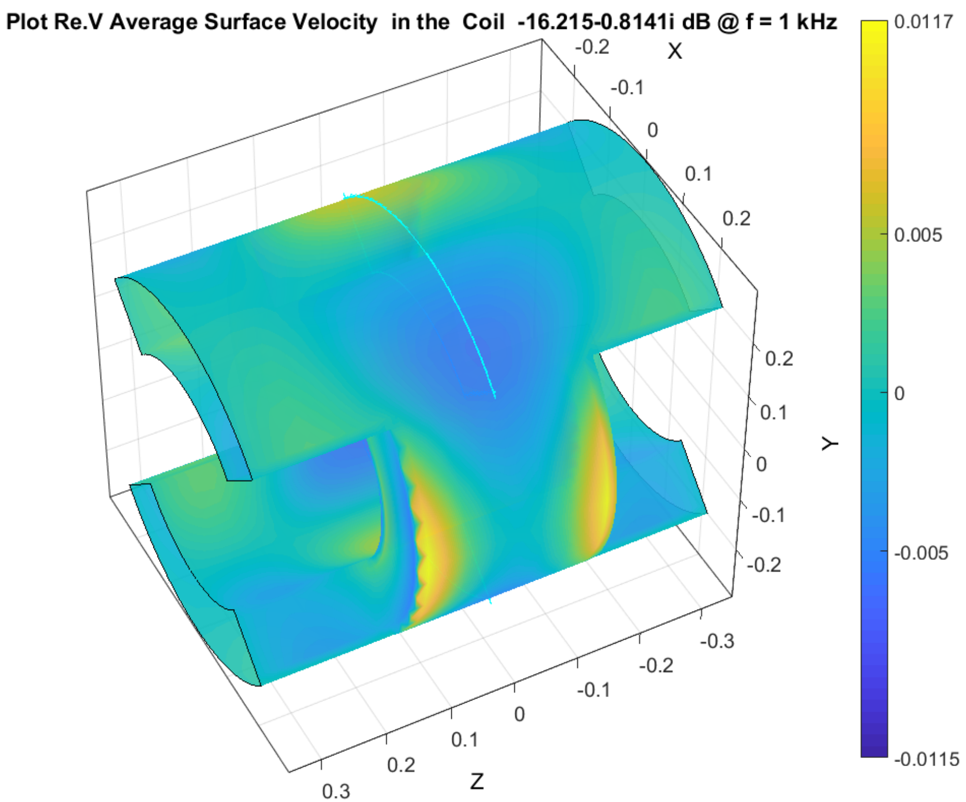
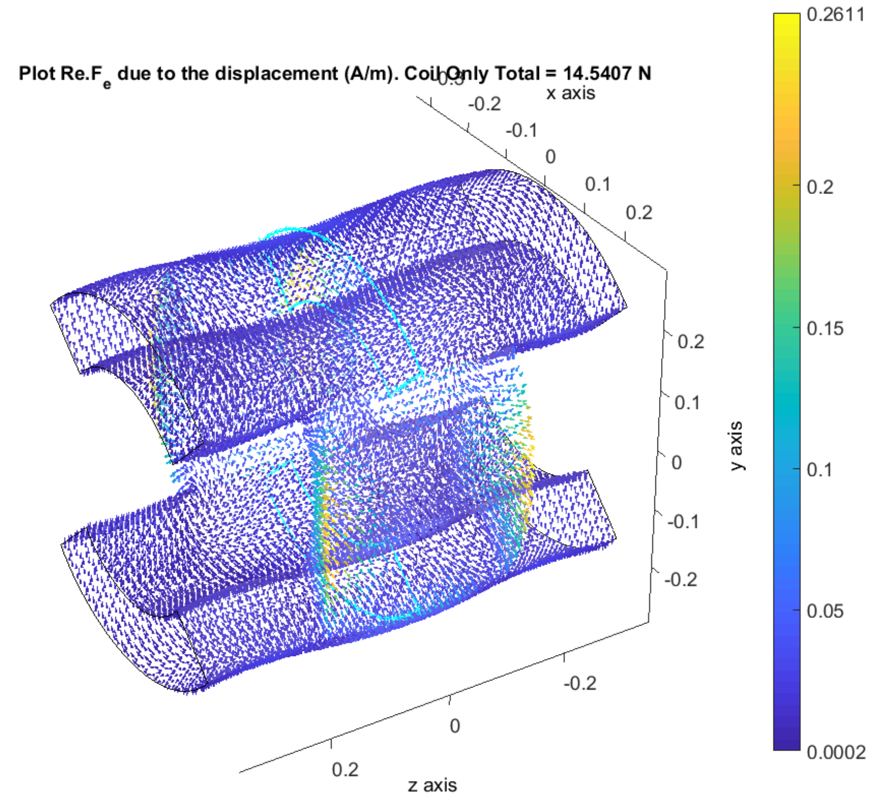
Hyper Vision Gradient Coil-X





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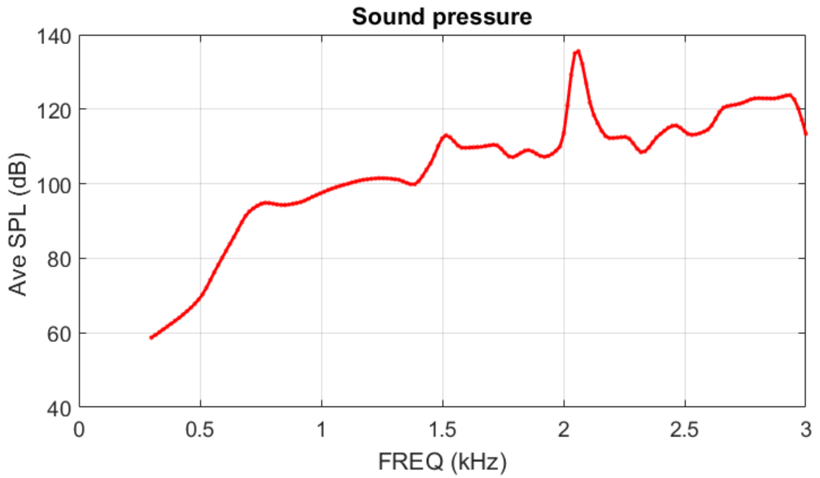
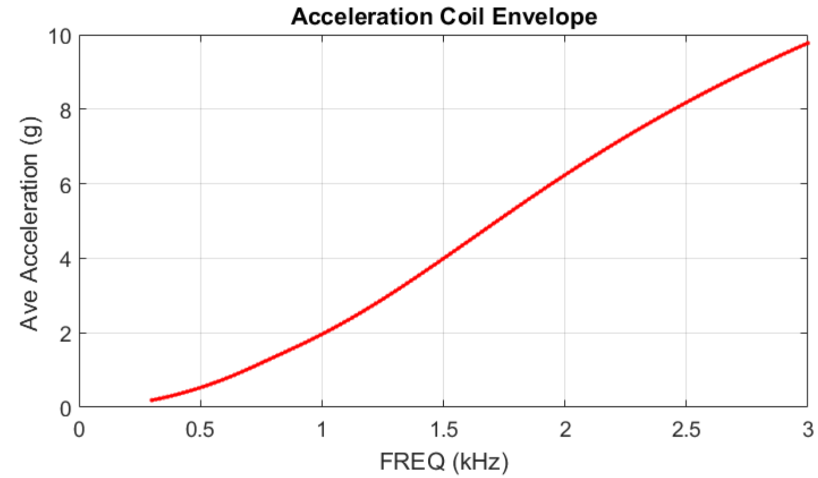
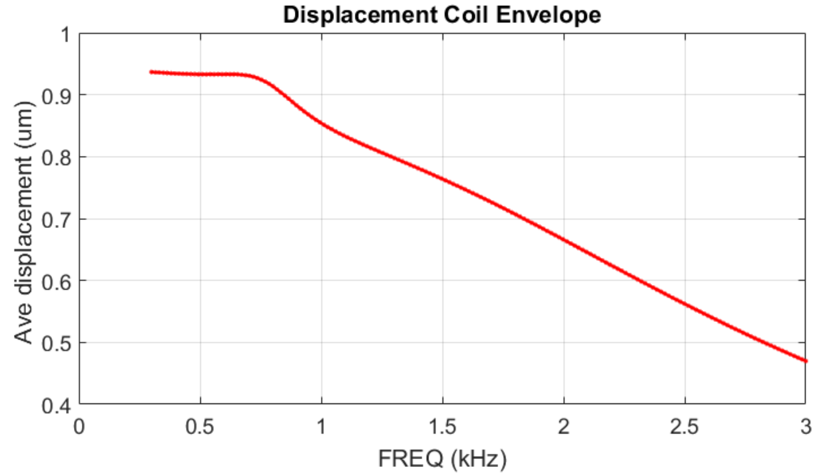
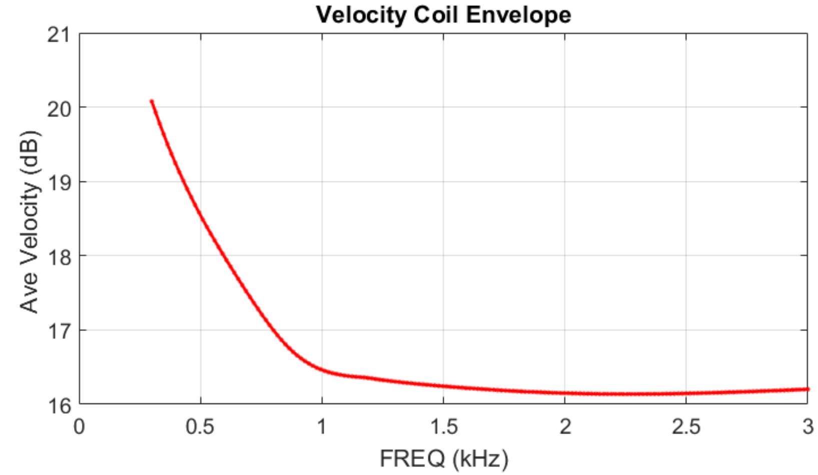
Hyper Vision Gradient Coil-X









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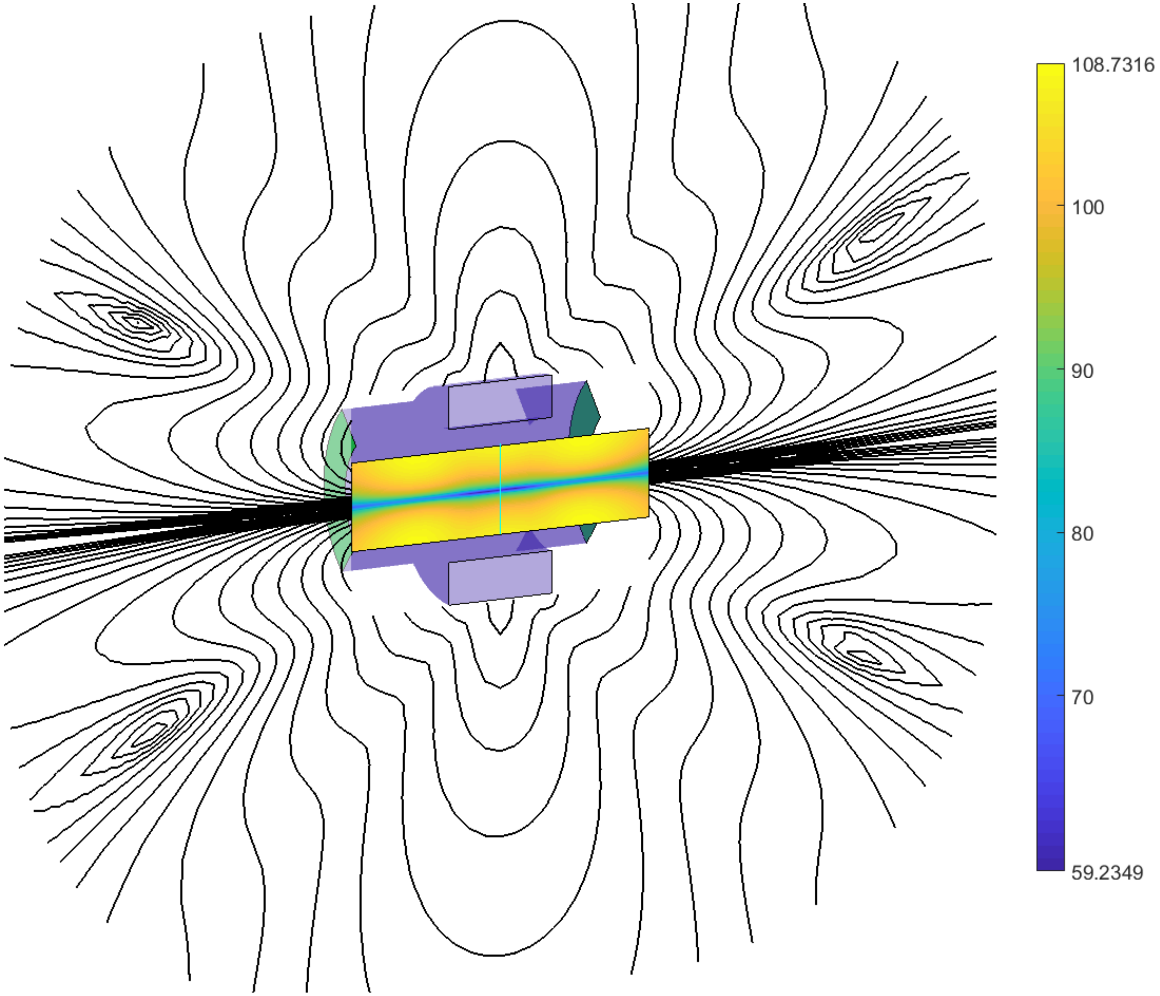
Hyper Vision Gradient Coil-X

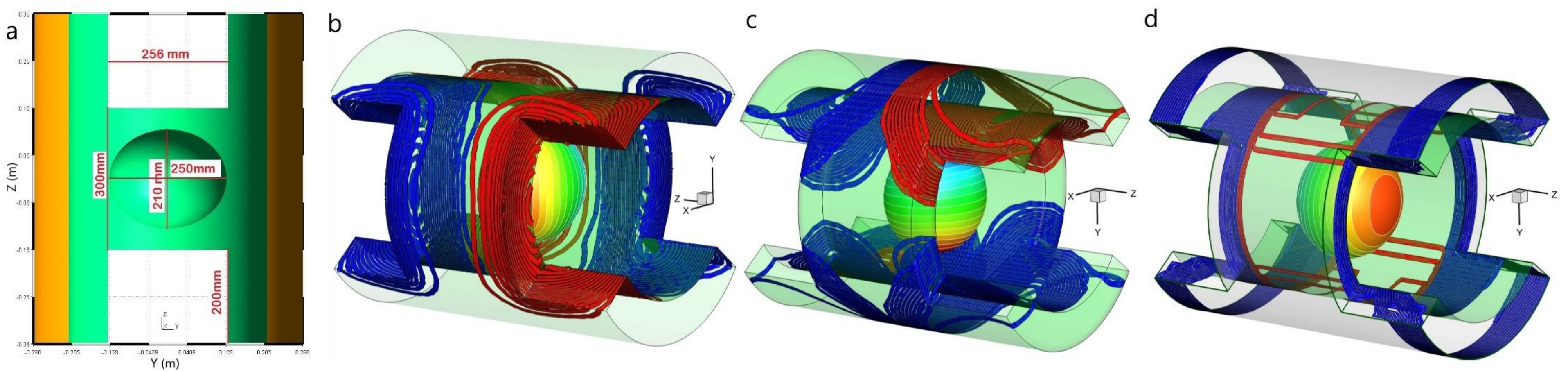


Sound pressure profile X coil (dB)@1kHz.

No cryostat was included.

Conclusion

The designing stage of a head scanner based on a 3T HTS magnet has been presented. The hyper-vision gradient coil producing 200 mT/m and nearly 1900 T/m/s to delve at the mesoscopic scale the connection between micro-vessels and brain tissue has been introduced. The two hyper-vision coil envelopes with standard ergonomics dimensions classifies as “connectome” gradient coils and would be the necessary boosting to bring UHF to clinical practice at its full potentiality.



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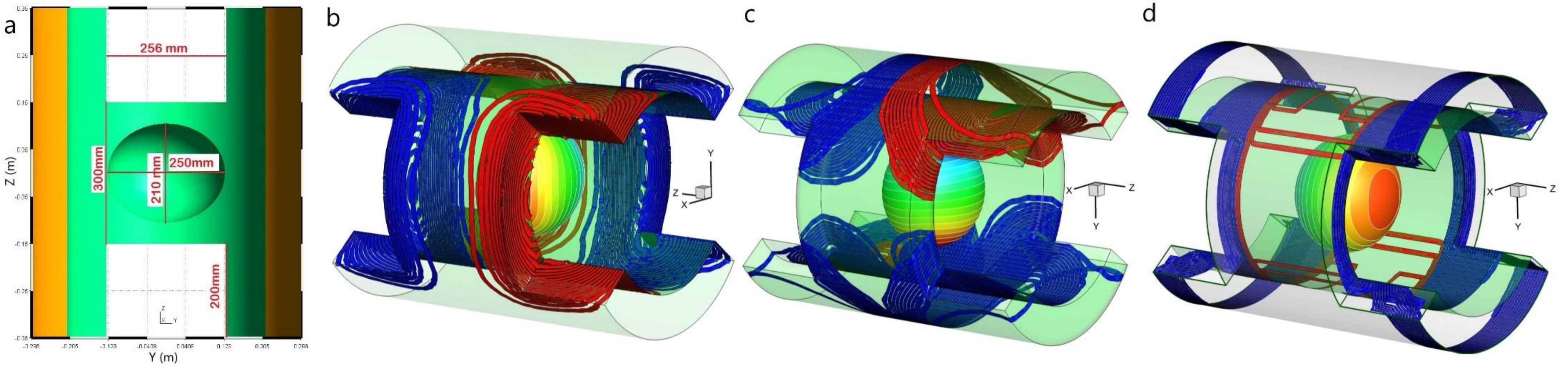
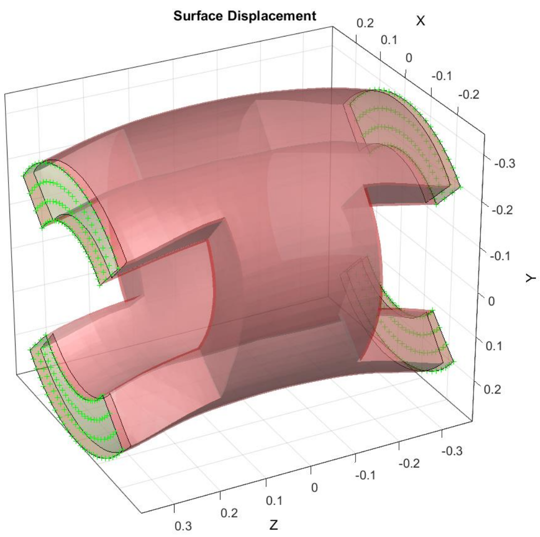
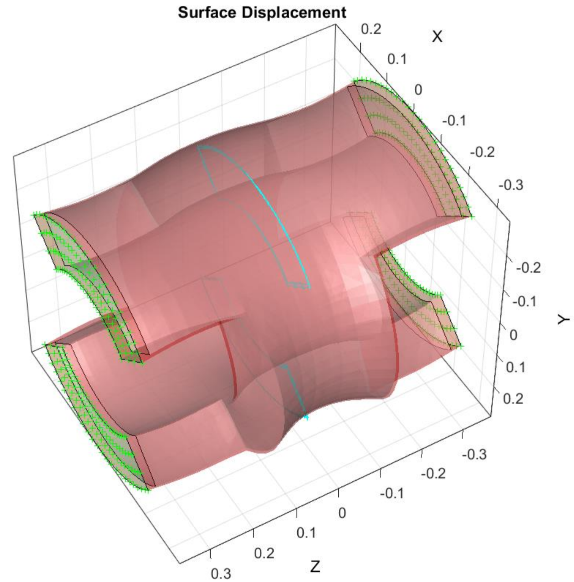
Thanks







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