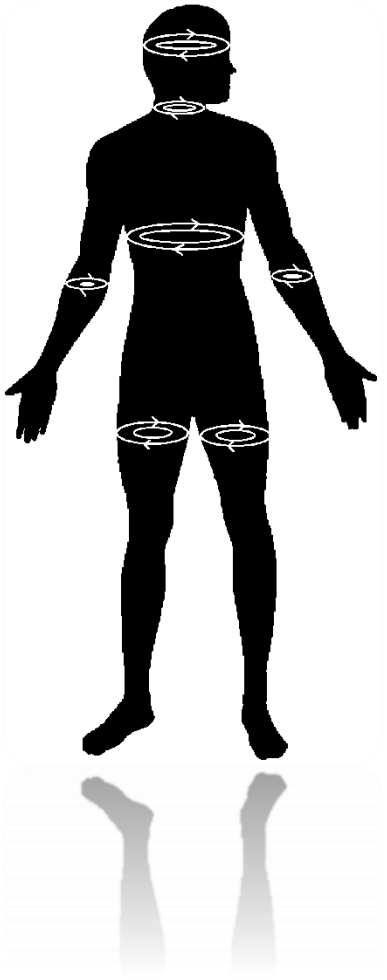
Safety Aspects for a Pre-clinical Magnetic Particle Imaging Scanner

Gael Bringout, Hanne Wojtczyk, Mandy Grüttner,
Matthias Graeser, Wiebke Tenner, Julian Hägele,
Florian M. Vogt, Jörg Barkhausen, Thorsten M. Buzug

Institute of Medical Engineering
University of Lübeck
Director : Prof. Dr. T. M. Buzug

INTRODUCTION



What May Be Unsafe in an MPI Scanner ?

- Acoustic noise shouldn't be a problem
  - As used frequency are above the Human earing level and no pulses are applied, like in MRI
- Patient heating shouldn't be a problem
  - If the frequency is kept below 100 kHz
- High field amplitude shouldn't be a problem
  - If we don't have field higher than 1 T
- Peripheral Nerve Stimulation (PNS) is still under investigation
  - Still under investigation for MRI also

How Stimulation Happens?

- An induced electric field may activate nerves
  - Induced electrical field amplitude based on Faraday's law of induction :

$$\oint_{\partial S} \boldsymbol{E} d\boldsymbol{l} = \int_{S} \frac{\partial}{\partial t} \boldsymbol{B} d\boldsymbol{A}$$

$\boldsymbol{E}$: electric field

$\boldsymbol{B}$: magnetic field

$\boldsymbol{S}$: surface bounded by contour $\partial \boldsymbol{S}$

$d\boldsymbol{A}$: infinitesimal vector element of surface $\boldsymbol{S}$

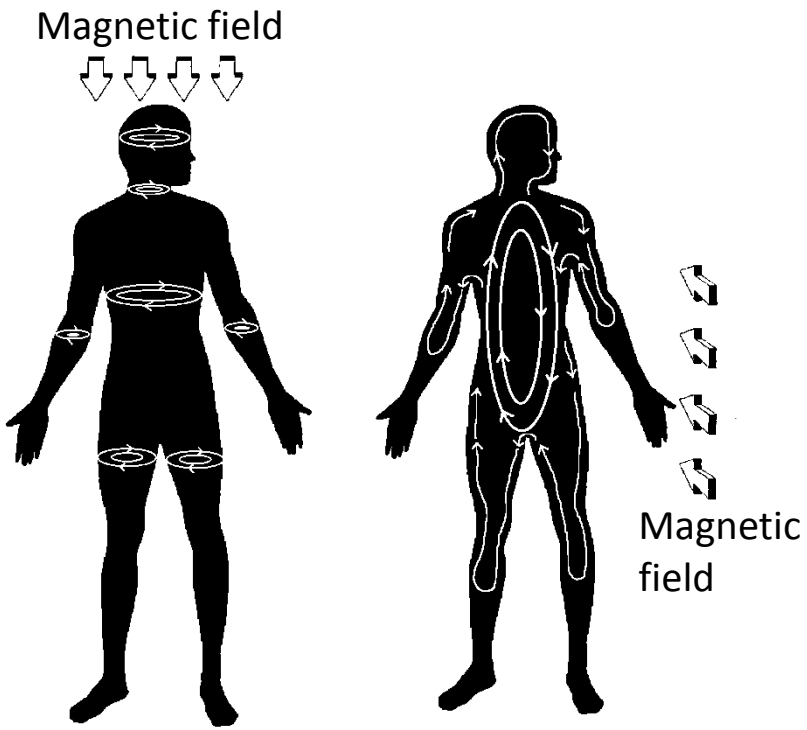
$d\boldsymbol{l}$: infinitesimal vector element of contour $\partial \boldsymbol{S}$

  - For a sphere :

$$E_i = \frac{r}{2}\left(\frac{\partial ||\boldsymbol{B}||}{\partial t}\right)$$

$\boldsymbol{E_i}$: induce electric field

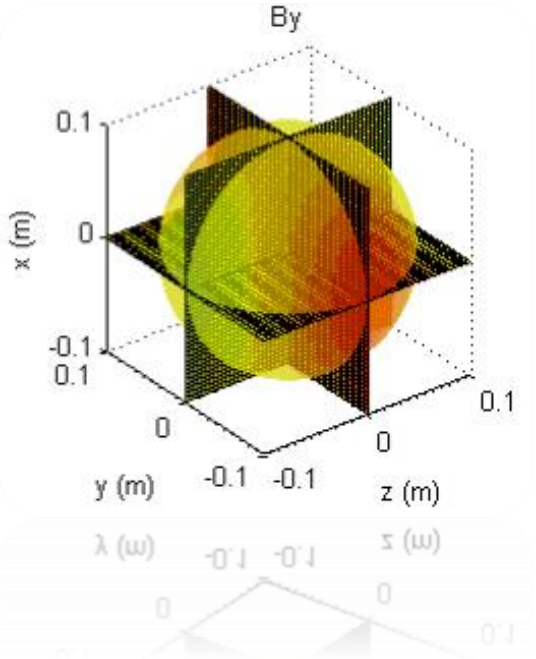
r : radius of the sphere



Induced electric fields from magnetic fields having two differents orientation

How to Evaluate the PNS Threshold?

- The stimulation thresholds are unclear
- Experimental method
  - E. Saritas et al. approach
    - 1D, solenoid, max 320 mT, inner diameter max 11 cm
    - 1D, solenoid, max 160 mT, inner diameter max 19 cm
- Cell level calculation
  - J. Bohnert et al. approach
    - 1D, Helmholtz coil pair, 20 mT, inner diameter 70 µm
- Simplified patient level calculation
  - Our approach
    - 3D, Open scanner, distance between coils 20 cm
- Complete patient level calculation

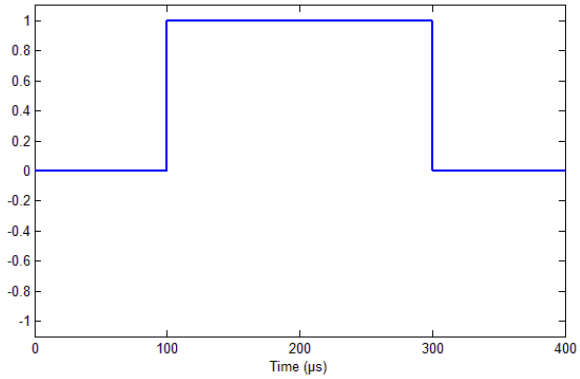


METHOD & CALCULATION

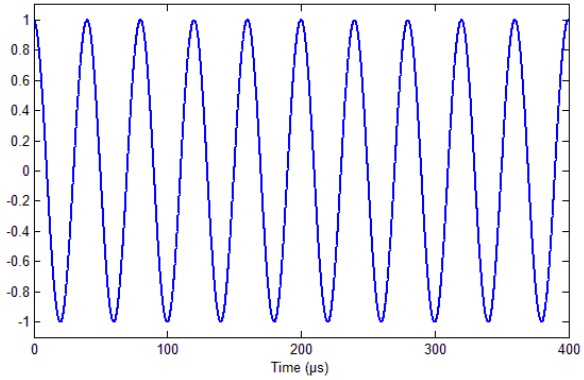
What Do we Need to Know?

- Patient geometry
  - Sphere with radius of 10 cm and 4 cm
- Field amplitude
  - There is no standard or convergent coils topology in MPI
- Signals shape
  - Pulse or Pulse train
  - Continuous cosine
  - 3D MPI Signal

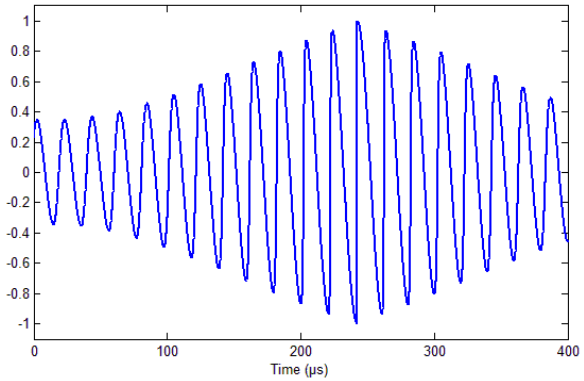
0.2 ms pulse in MRI



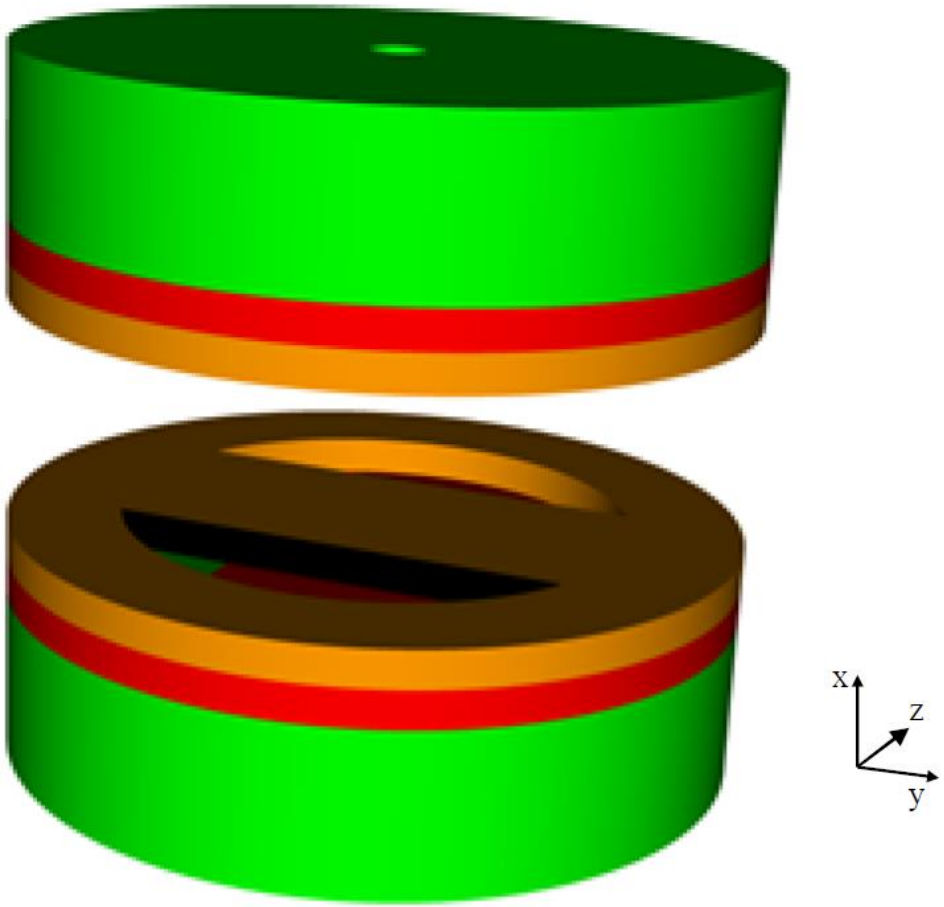
25 kHz Continuous cosine



3D MPI signal



An Open Scanner



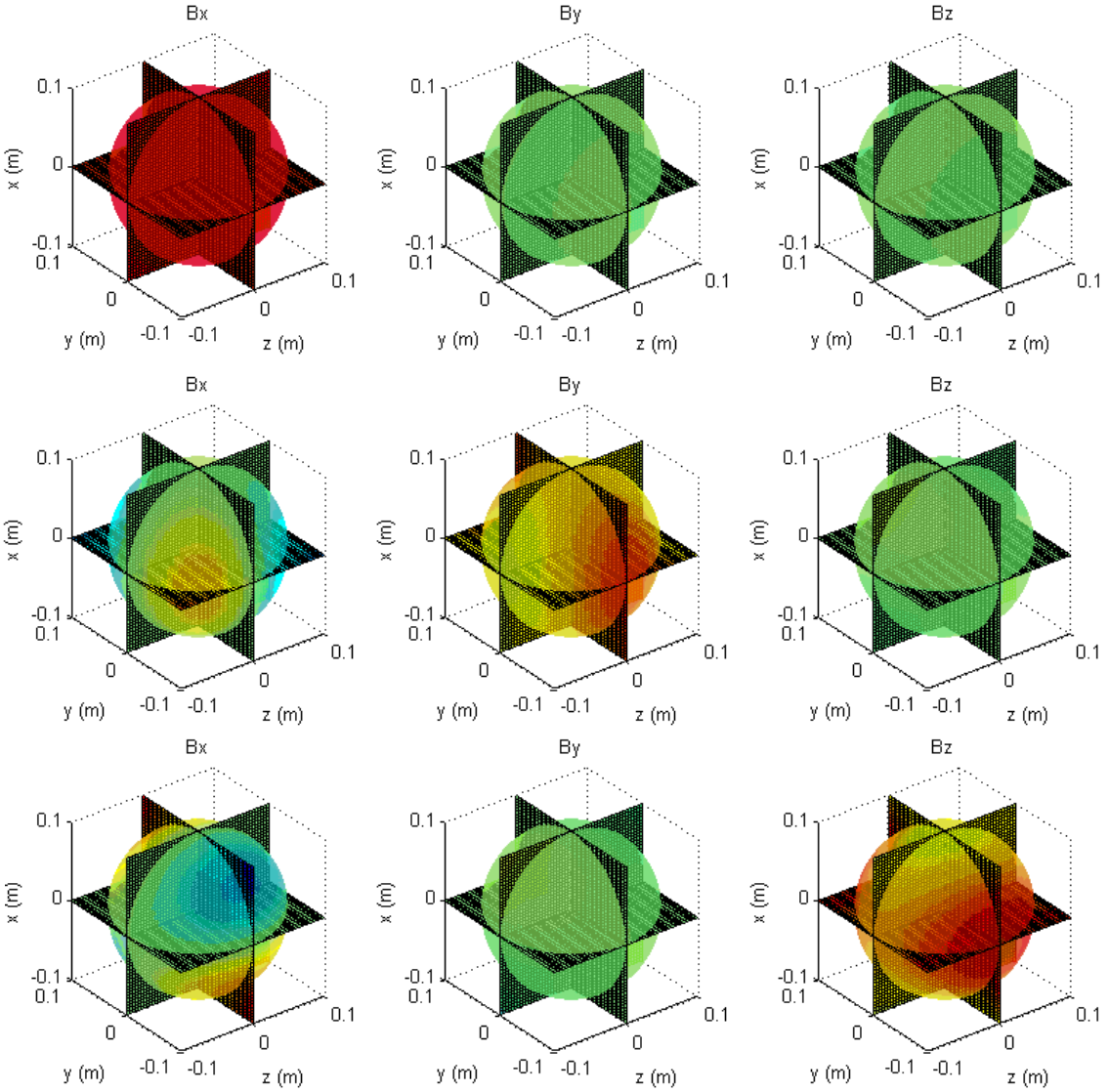
Sattel et al., Open Coil Arrangement for Interventional Magnetic Particle Imaging, ISMRM, **(2010)**

Generated Magnetic Field Amplitude

x Driving coil

y Driving coil

z Driving coil



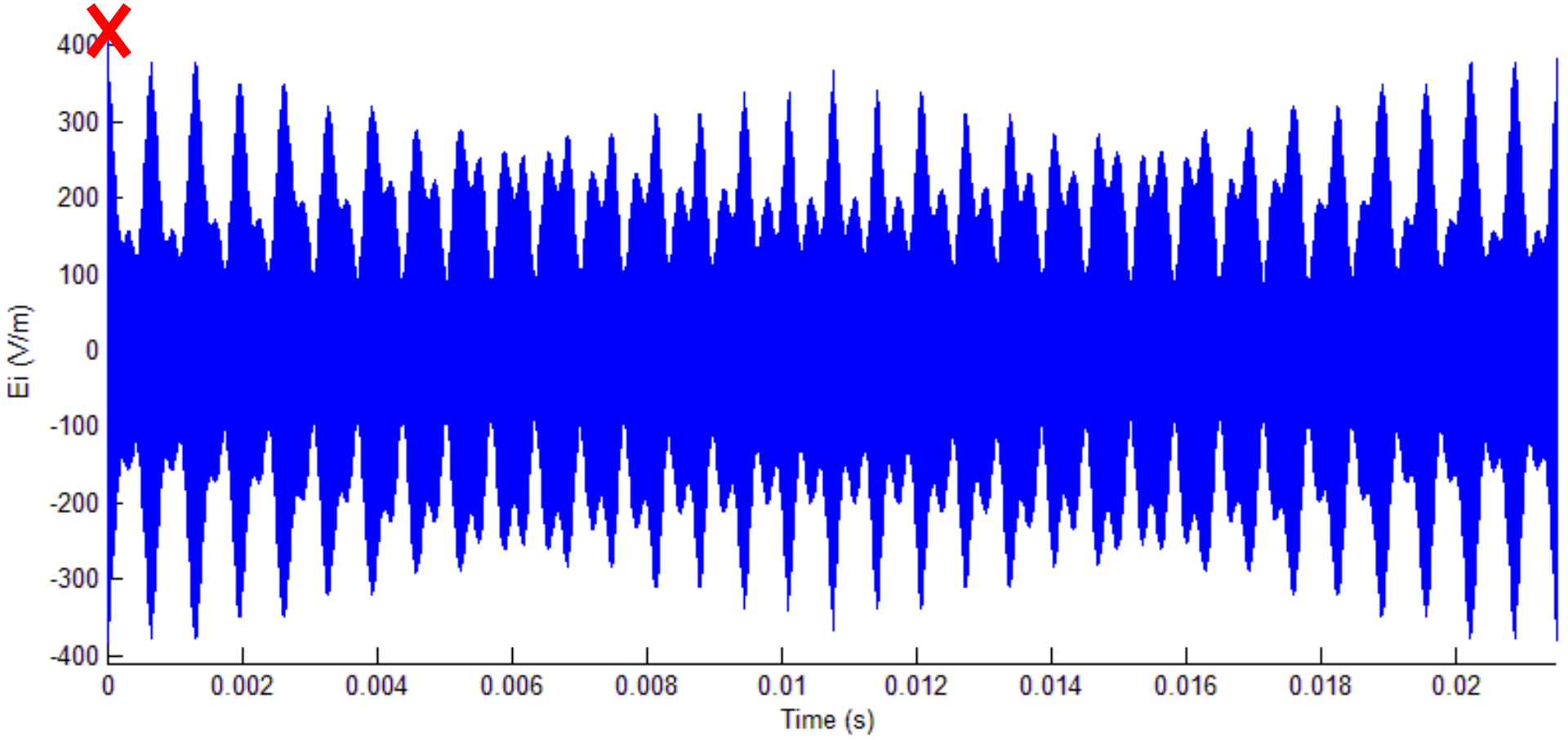
Generated Magnetic Field Amplitude

- Mean absolute value of the field in the sphere

	B_x (mT)	B_y (mT)	B_z (mT)	B_{abs} (mT)
x driving coil	40	0	0	
y driving coil	3	18	0	
z driving coil	1	0	21	
Sum of fields	44	18	21	52

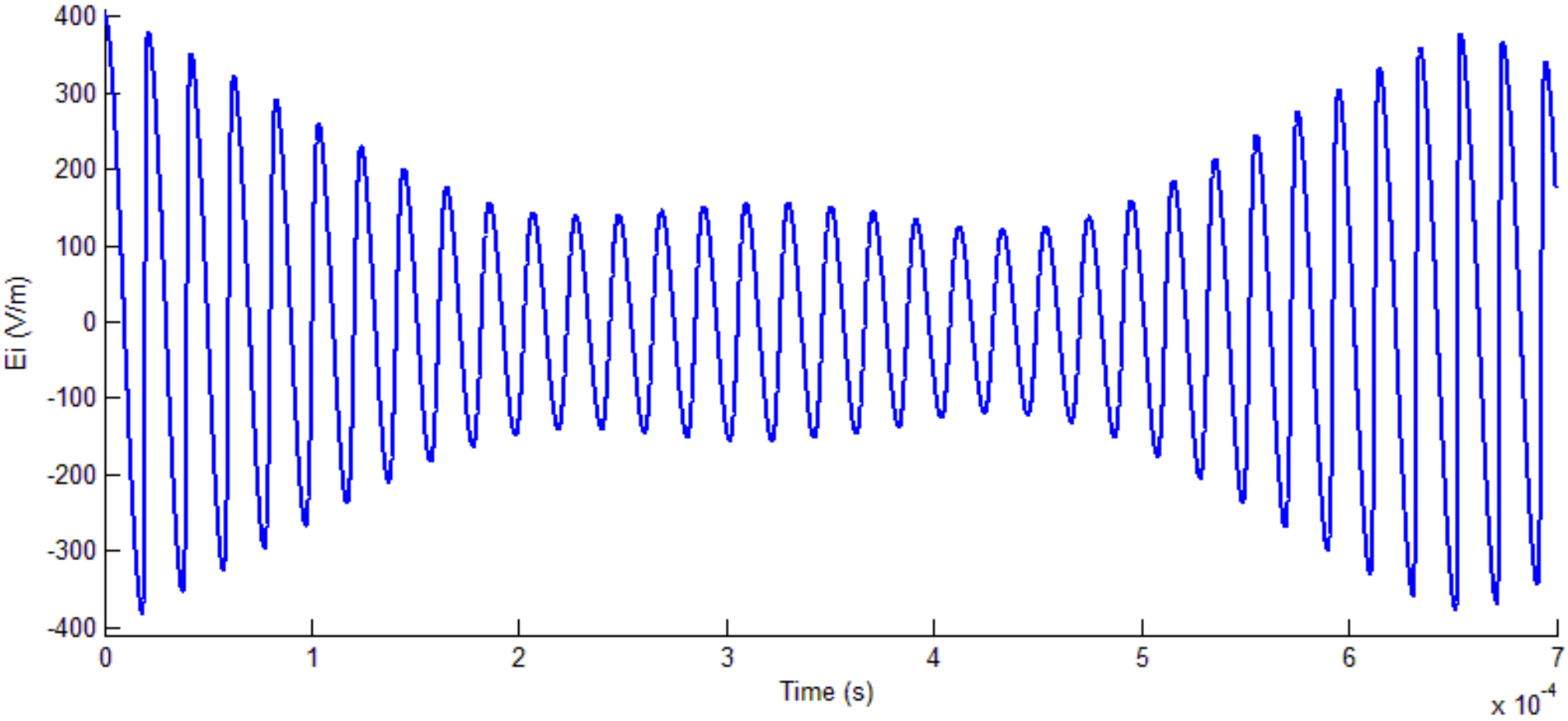
Induced Electrical Field

- Ground frequency : 24.51 kHz, 25.25 kHz and 26.04 kHz



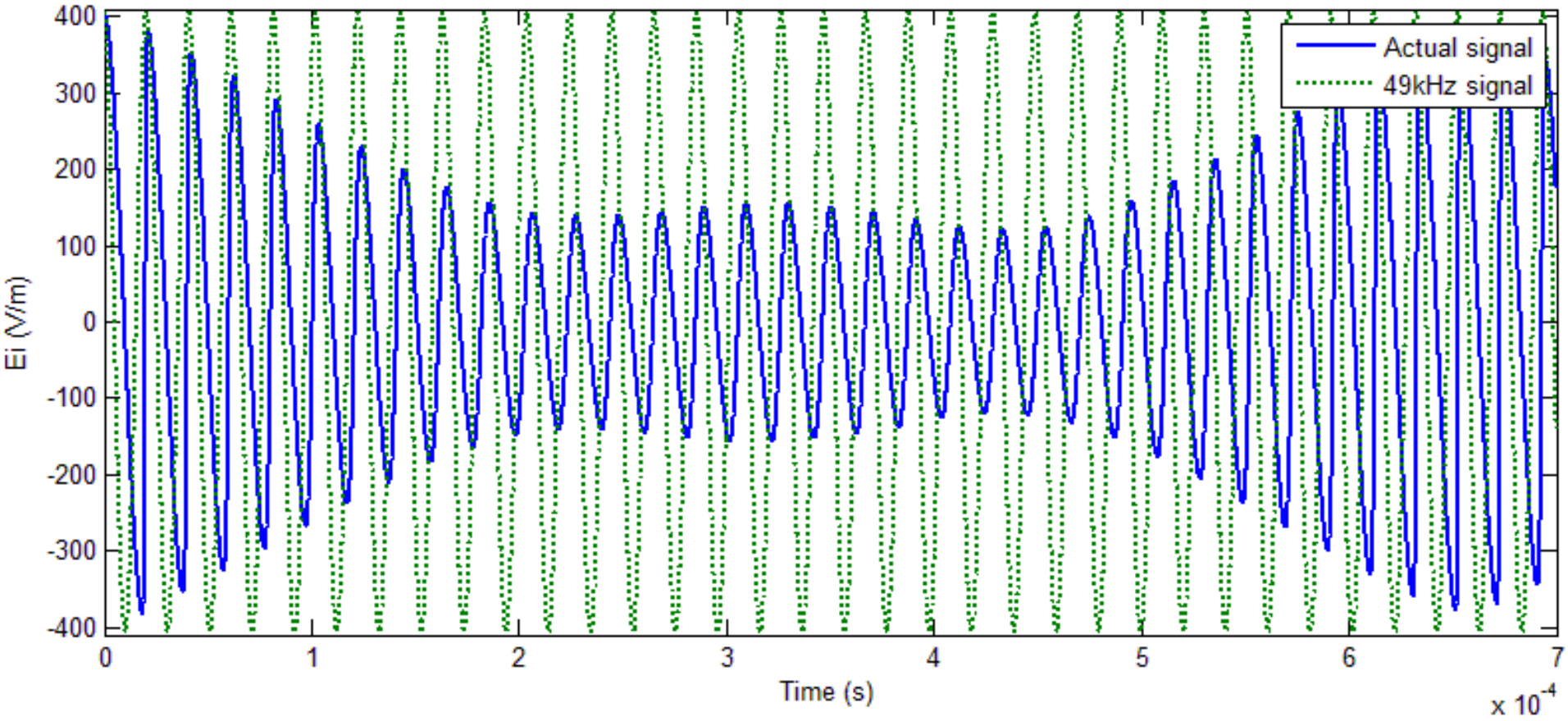
Induced Electrical Field

- Ground frequency : 24.51 kHz, 25.25 kHz and 26.04 kHz



Induced Electrical Field

- Ground frequency : 24.51 kHz, 25.25 kHz and 26.04 kHz



Summary

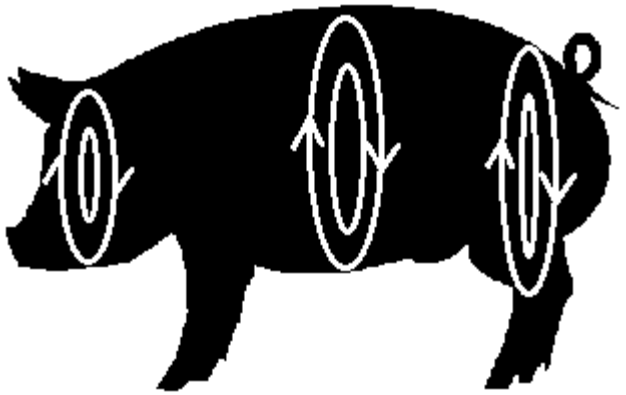
- We have :
  - Sphere of radius 10 and 4 cm.
  - Magnetic fields value is based on the mean absolute value of the magnetic field in the 10cm radius sphere
  - A single, continuous sinusoidal signal at 49 kHz
- We induce :
  - Electrical field amplitude in the body : 407 V/m
  - Electrical field amplitude in the heart: 163 V/m

GUIDELINES

Thresholds for PNS

- ICNIRP* (2010) for 49 kHz continuous sinus
- Reilly model (1991) : $E_t = E_0 \left(\frac{f}{f_e}\right)^{0.9}$
  - E_0 = 7.3 V/m, : minimum E-field threshold
  - f = 49 kHz : actual frequency
  - f_e = 5400 Hz (Body, in-silico model)
  - f_e = 500 Hz (Body, experimental review)
  - f_e = 120 Hz (Heart, experimental review)

*International Commission on Non-Ionizing Radiation Protection



RESULTS & CONCLUSION

Results

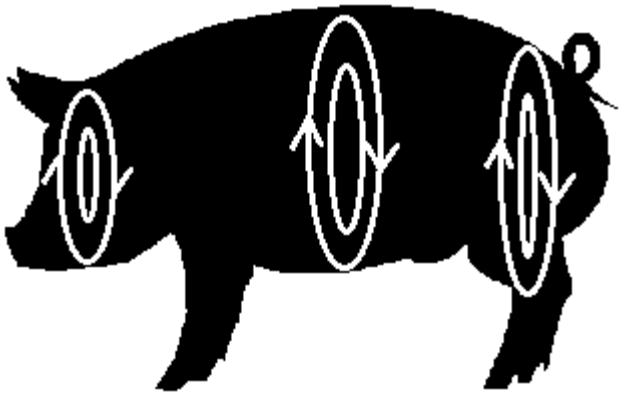
		Our case	Guidelines		
Body		Model	Exp. review	Reilly's model	ICNIRP
	E (V/m)	406	452	53	~~170~~
Heart		Model	Exp. review		
	E (V/m)	163	1634		

Conclusion

- No heart stimulation risk in our scanner for 3D at those amplitudes
  - At least an order of magnitude as safety factor
- PNS will likely happen

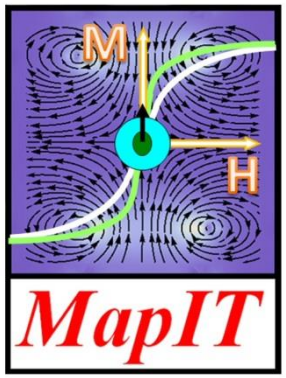
Future work :

- PNS evaluation on the medical staff around the scanner
- Further experimental tests



Thank you for your attention!

Project



Funding

Bundesministerium
für Bildung
und Forschung

Magnetic Particle Imaging Technologie (MAPIT) . *FKZ*: *13N11086*