Very Low Field MRI with Giant Magnetoresistance based sensors

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Target audience:
MR physicists and instrumentation developers in MRI interested in magnetic field sensors and very low field MRI.

Purpose:
Very low field MRI, using static fields in the mT range, has a number of important advantages. Light weight and open setups can be built without superconducting coils and at minor cost. In addition issues such as metallic implants restriction, susceptibility artefacts and gradient acoustic noise are negligible compared to high field applications.
However very low field applications are limited by low sample polarization and poor detector sensitivity resulting in low signal to noise ratio (SNR), poor resolution and long acquisition time. Several systems are presently developed using SQUIDs detection[1]. Our approach is based on mixed sensors devices[2], that couple a Giant Magneto-Resistance with a superconductive loop, offering high sensitivity (~10 $fT/\sqrt{Hz}$) that outperforms Faraday detection at low frequencies. The purpose of this study is to demonstrate the feasibility of very low field MRI using mixed sensors in an open, non shielded environment.

Methods:
Mixed sensors [Fig. 1] were integrated into a low field MRI prototype. A static field of 7.5mT (10 ppm homogeneity on a 5x5x5cm volume, 4 coils setup) and low power linear gradients (10 $\mu T.cm^{-1}.A^{-1}$) were generated using resistive coils. NMR signal detection was performed using a flux transformer coupling the room temperature sample to the cryogenic mixed sensor operating at 77K. We performed three dimensional images of a finger. A single slice was acquired using a spin echo sequence (TE/TR 18/200ms, FA 90°, resolution of 1x1x4mm, 50 averages per line, 5 min acquisition time).

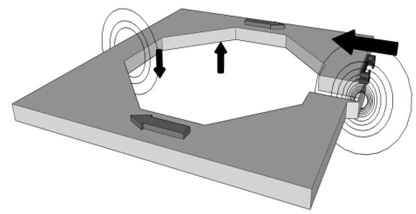

Figure 1 : Mixed Sensor

Results:
The mixed sensors were not affected by static magnetic field, gradients and RF pulses even in the absence of magnetic shielding and without RF switch. The total acquisition time of a 3D image was 20 min for a volume of 5x2x2cm. Fat and marrow present a strong signal while bones and tendons have a low signal [Fig.2]. Those T1 weighted images present a signal to noise ratio of 3.9. The mean relaxation time T1 on the entire slice was about 132ms (+-16ms).

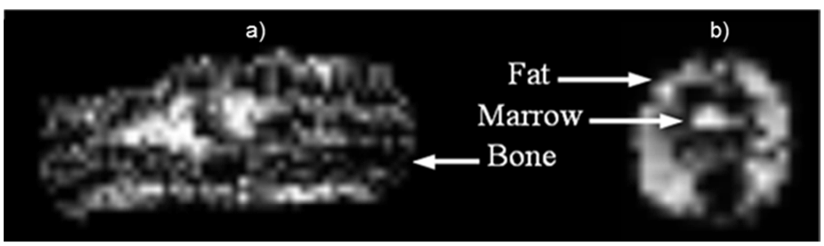

Figure 2 : a) Sagital and b) axial slice of a finger at 7.4

Discussion:
At 319 kHz (7.5mT), this untuned detection system offers a sensitivity close to tuned coils (Q = 100) with no bandwidth limitation. SNR could be enhanced using higher quality sensors as we are still limited by detection's noise instead of body's noise. As expected, T1 at very low field are shorter in comparison to high field but the ratio between tissues is approximately respected.

Conclusion:
A precise relaxometry study of healthy and diseased tissues at those frequencies in a clinical environment would be an important step in the development. Recent studies have shown that relaxation mechanisms at low field could lead to new contrasts enhancement[3] widening perspectives for tumour investigation. Further research should concentrate on the use of efficient acquisition sequence in harmony with very low field specificity. A resized setup is also developed in parallel for brain imaging.

References:
1. Mossle M. and al. *SQUID-detected in vivo MRI at microtesla magnetic fields*. IEEE Transactions on Applied Superconductivity. 2005; 15(2): 757–760.
2. Pannetier M. and al. *Femtotesla magnetic field measurement with magnetoresistive sensors*. Science. 2004; 304: 1648–1650.
3. Busch S. and al. *Measurements of T1-relaxation in ex vivo prostate tissue at 132 μT*. MRM. 2012; 67(4):1138-1145.