Navigation with Hall Sensor Device for Interventional MRI

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Introduction

The incorporation of small RF coils into the tip of interventional devices can be used for active localization (1). In this work a small Hall effect sensor is used for spatial localization. The measured Hall voltage is proportional to the local magnetic field (and its orientation relative to the sensor), composed of the main field B_0 and the spatially dependent magnetic field gradient. Since all switched gradients during an imaging sequence are predetermined and known the spatial position of the sensor can be calculated from the measured Hall voltage.

Theory

The magnetic field **B**(**r**) is composed of the main field B_0 in z-direction plus 3 independent, linear magnetic field gradients G along x, y, and z direction. If (s1,s2,s3) is the sensitivity of a 3D Hall sensor array, and (θ,φ) its orientation in polar coordinates the detectable Hall voltage $\mathbf{U_H}(\mathbf{r})$ including Maxwell terms becomes

$$\vec{U}_H(\vec{r}) = \begin{pmatrix} s_1 & 0 & 0 \\ 0 & s_2 & 0 \\ 0 & 0 & s_3 \end{pmatrix} \begin{pmatrix} \sin\theta\cos\varphi & \cos\theta\cos\varphi & \sin\varphi \\ \sin\theta\sin\varphi & \cos\theta\sin\varphi & -\cos\varphi \\ \cos\theta & -\sin\theta & 0 \end{pmatrix} \begin{pmatrix} -\frac{1}{2}G_z & 0 & G_x \\ 0 & \frac{1}{2}G_z & G_y \\ G_x & G_y & G_z \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix}.$$

From the three measured time courses Ux, Uy, Uz and the known time courses of the switched gradients Gx, Gy, Gz the spatial position as well as orientation of the Hall sensor can be determined. The accuracy of localization depends on the noise and stability of the Hall sensor and amplifiers.

Experiments

A prototype Hall device (HW-105C, sensitivity 2V/T at 15 mA Hall current, AKE, Tokyo, Japan) with a single sensitivity direction was connected to four, pairwise twisted copper wires (PU insulated, 100 µm), see Fig.1. To reduce induction of RF energy into the copper wire small ferrite cores have been mounted every 4 cm along the wire. The Hall voltage was amplified with an ac-coupled instrumental amplifier, followed by a 16-Bit ADC (PCI-6014, National Instruments). Hall voltage was measured at different spatial positions and orientations during the run of constant, bipolar gradient pairs as well as during a balanced SSFP imaging sequence.

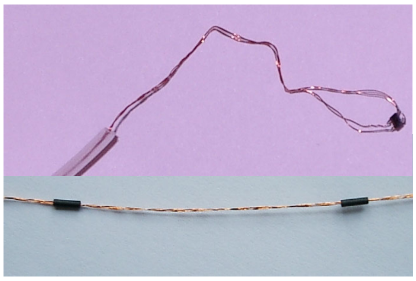

Fig. 1: Top: Hall sensor connected to copper wire. Bottom: Cylindrical ferrite cores attached every 4 cm to reduce coupling of external RF-field.

Results

Fig. 2a shows the Hall voltage (5 µs sampling rate) generated by a switched phase encoding gradient in z-direction (ramp 300 µs, flat top 500 µs at 20 mT/m). The sensor was positioned +5 cm offcenter. The change of the Hall voltage is ±2 mV with a noise component of about 1.0 mV_{eff}. The noise induced by the sensor and amplifier translates into an error of the spatial position of roughly ±2.5 cm at 20 mT/m. However, averaging of several phase encoding cycles may easily increase the spatial accuracy to less than ±2 mm. For example, assuming a TR of 5.2 ms as shown in Fig. 2a, averaging of 128 phase encoding steps as typically used for real-time imaging results in an increase of spatial accuracy by a factor of 11, while the temporal resolution is still about 0.7 sec (128 x 5.2 ms). Fig. 2b shows the averaged time course for a constant phase encoding amplitude during 128 steps. Fig. 2c shows the measured sensor position as a function of the z-position. Indicated error bars correspond to ±0.1mV or ±2 mm at 20 mT/m.

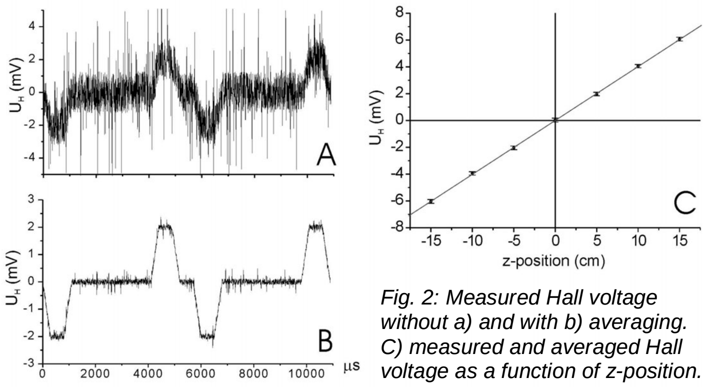

Fig. 2: Measured Hall voltage without a) and with b) averaging. C) measured and averaged Hall voltage as a function of z-position.

Conclusion

Our preliminary data demonstrate the possibility to detect the spatial position of a Hall sensor with an accuracy of about 2 mm during the run of an imaging sequence. A potential problem is the use of conducting wires where electric coupling with the transmit rf field may lead to severe heating. Mounting of small ferrite cores along the wire as used here, or using optical signal transmission (2) will be investigated.

References

(1) Dumoulin CL, Souza SP, Darrow RD. MRM 1993;29:411-15. **(2)** Bock M et al. ISMRM 2003, p. 231.