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Design of a reconfigurable endoluminal coil using MEMS switches

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Synopsis

Endoluminal Magnetic Resonance Imaging (MRI) is an alternative solution to conventional MRI, which is still not sufficient to image the bowel and colon wall. However, it mainly suffers from coil-sensitivity-map variations with coil-orientations within respect to the main magnetic field (B0). The purpose of this work was to study numerically different coil-geometries and their performances when positioned in different orientations regarding B0. From the simulation results, a solution of a reconfigurable endoluminal-coil using four MEMS switches is proposed. Electro-Magnetic (EM) simulation demonstrated the feasibility to reduce the coil-sensitivity variations by using a combination of Single-loop (SL) and Double-Turn-Loop (DTL) configurations.

Introduction

Inflammatory bowel diseases can evolve to colorectal cancer¹. Although the image quality of MRI based on array of external receiver-coils (as measured through signal-to-noise ratio, SNR) has improved, it is still unable to depict thin and deep colon wall layers. Previous works have demonstrated the value of the endoluminal imaging based on miniature internal (endoluminal) receiver-coils²⁻⁵. Such coils provide a high local SNR in the vicinity of the region of interest⁶. However, because an endoluminal-coil will have to be introduced into the body, within natural orifices, and to navigate within the bowel, its orientation will change with respect to B0⁷. This implies coil sensitivity-map variations and thus image quality degradation⁸. Hence, it could be relevant to adapt the coil-geometry with its orientation which is the goal of this work by designing coil-geometry that can be achieved using Micro Electro-Mechanical Switches (MEMS) technology developed by GE Healthcare company⁹.

Methods

We used EM software (FEKO), based on the method of the moment, to simulate different endoluminal loop-geometries, mainly, based on 1mm wide copper strips. The dimensions were chosen taking into consideration the eventual insertion in the colon. The designs were: single-loop 2D-geometries (rectangular and diagonal loops: 5x47mm² and 7.07x47mm², respectively); and different series and parallel double turn-loop 3D geometries (5x47mm² each turn-loop) with opposite or similar current directions which designed on two opposite faces with 5mm loop spacing. The z-axis was aligned along the length of the coil and the B0 field direction. The imaging plane was always perpendicular to the coil-plane which is where magnetic field H1-maps were calculated. Using Matlab, extracted H1-components data were used to deduct the magnetic induction B1-maps. Then, we evaluated the rotation effect of each loop-coil about x-axis and/or y-axis with angles of 15°, 30°, 45°, 60° and 90° with respect to B0. This was realized by applying 3D-transformations, based on rotation matrices. The analysis method was based on the quantification of B1-uniformity and intensity on concentric circles of radius 5, 8 and 10mm which is the targeted colon wall imaging area. For each distance, B1-intensity values were sampled every 1°. Then, the mean B1-values as well as the standard deviation of B1 were calculated at each reference distances and tilted orientations (figure 1).

Results

Two complementary loop-configurations emerged from the simulation set as offering improved performance and robustness to orientation: Diagonal SL and DTL based on opposite current direction. Table 1 summarizes the EM simulation results of SL and DTL coils, respectively, at reference orientation and the evaluation results of the coil-orientation effect with different angle rotations about the x-axis and/or y-axis at different distances from the coil. The mean of B1-values (B1-intensities) of both coils was higher in the vicinity of the loop-conductors and drops-off rapidly with distance from the coil-center. Also, they were higher for the SL than for the DTL. Despite this penalization of the DTL, it overall provided averages superior to 10µT. The standard deviations (SD) of B1-values of the DTL were still the lowest (~30%) close to the coil (5mm). At 8 and 10mm, the SD-values of the SL were the lowest around the reference orientation (<30°). Beyond this angle, the SD values of the DTL were the lowest.

Discussion

At the reference orientation and for orientations up to 30°, the SL coil could be used taking advantage of its higher signal intensity and acceptable radial-uniformity. For angles superior to 30°, the DTL bring some advantages be used since it still provides sufficient B1-sensitivity while offering better radial-uniformity. According to these results, combining both SL and DTL leads to the design of an endoluminal-coil able to work with multiple configurations according to the coil-orientation. This can be achieved by using MEMS switches to change the current pathway from SL to DTL and back (figure 2).

Conclusion

In this work, we focused on improving robustness of endoluminal coil-sensitivity to coil-orientation with respect to B0. EM simulations demonstrated that it is possible to reduce the dependency of the sensitivity to coil orientation through a reconfigurable coil based on MEMS switches. The geometry was mainly based on four controllable and switched conductors that allow to design two different loop-configurations (SL and DTL) that will be activated depending on the actual coil-orientation in B0. Future work will focus on building a prototype and on its characterization on both experimental bench and imaging set-up. Losses to asses signal-to-noise ratio with the different geometries will also have to be addressed. Reconfigurable coil-geometry that can be modified during the navigation inside the colon appears an attractive solution for colon wall analysis.

Acknowledgements

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References

1. Munkholm P. The incidence and prevalence of colorectal cancer in inflammatory bowel disease. *Aliment Pharmacol Ther* 2003; 18:1-5.
2. Hurst GC, Hua J, Duerk JL, Cohen AM. Intravascular (catheter) NMR receiver probe: Preliminary design analysis and application to canine iliofemoral imaging. *Magn Reson Med* 1992; 24:343-357.
3. Gilderdale DJ, deSouza NM, Coutts GA, et al. Design and use of internal receiver coils for magnetic resonance imaging. *Br J Radiol* 1999; 72:1141-1151.
4. Beuf O, Pilleul F, Armenean M, Hadour G, Saint-Jalmes H. In vivo colon wall imaging using endoluminal coils: Feasibility study on rabbits. *J Magn Reson Imaging* 2004; 20:90-96.
5. Dorez H, Ratiney H, Canaple L, et al. In vivo MRS for the assessment of mouse colon using a dedicated endorectal coil: initial findings. *NMR Biomed* 2017; 30:e3794.
6. Metzger GJ, van de Moortele P-F, Akgun C, et al. Performance of external and internal coil configurations for prostate investigations at 7 T. *Magn Reson Med* 2010; 64:1625-1639.
7. Atalar E, Bottomley PA, Ocali O, et al. High resolution intravascular MRI and MRS by using a catheter receiver coil. *Magn Reson Med* 1996; 36:596-605.
8. RAKI H, Saniour I, Robb F, Souchay H, Lambert S, Beuf O. Characterization and comparison of RF MEMS switch for active detuning of endoluminal receiver coils. In *ESMRMB 2017 Congr. Barcelone, Spain*; 2017.
9. Spence D, Aimi M. Custom MEMS switch for MR surface coil decoupling. In *Proc 23rd Annu Meet ISMRM Tor Can*; 2015:704.

Figures

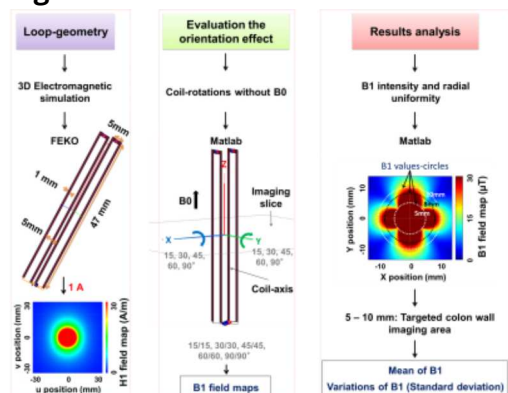


Figure 1. Different steps from the coil-design to the results analysis. On the left-hand side is the full wave electromagnetic simulation with FEKO software to get the magnetic field H1. On the middle-hand side is the evaluation of the coil-orientation effect on H1 distribution and thus B1 distribution by using Matlab software (3D-transformations based on rotation matrices). On the right-hand side is the result analysis corresponding to chosen criteria (signal mean and standard deviation at 5, 8 and 10mm from the center of the coil).

Loop design	Diagonal Single-loop (SL)						Opposite current Double-turn-loop (DTL)						
	Mean of B1 (µT)			Standard deviation of B1 (µT)			Mean of B1 (µT)			Standard deviation of B1 (µT)			
Comparison criteria	5 mm	8 mm	10 mm	5 mm	8 mm	10 mm	5 mm	8 mm	10 mm	5 mm	8 mm	10 mm	
Reference orientation	118.0	44.3	28.2	34.3	3.5	1.0	116.4	27.9	14.3	20.4	5.5	2.1	
About x-axis	15°	133.6	43.2	27.5	33.9	3.6	1.1	134.2	27.3	14.8	20.7	5.5	2.1
	30°	100.3	40.8	25.8	32.8	4.1	1.3	100.8	26.8	13.2	18.9	5.3	2.1
	45°	101.0	37.3	23.8	32.8	5.9	1.4	99.8	23.7	12.1	17.5	4.4	2.4
	60°	80.8	35.2	21.0	34.8	8.3	1.5	86.1	21.2	10.8	16.2	3.8	2.3
	90°	75.3	28.3	18.1	43.8	13.8	1.8	74.8	17.8	8.1	38.5	8.3	4.4
About y-axis	15°	136.3	43.9	28.8	33.7	3.5	1.0	134.7	27.6	14.2	20.4	5.5	2.0
	30°	130.9	42.1	26.9	32.3	3.7	1.4	109.1	26.5	13.4	20.2	5.5	2.0
	45°	102.4	38.0	25.8	31.7	5.1	2.7	100.8	24.3	12.6	21.7	4.4	2.3
	60°	91.9	35.1	23.5	33.4	7.7	4.0	90.3	21.9	11.3	24.2	5.4	2.8
	90°	71.2	28.4	18.2	43.4	13.7	8.5	74.8	17.8	9.2	38.94	8.3	4.6
About x/y-axis	15°/15°	136.4	43.8	27.8	34.0	3.5	1.1	135.0	27.6	14.2	20.4	5.5	2.1
	30°/30°	113.1	42.8	27.1	33.2	3.7	1.4	111.8	26.8	13.8	20.1	5.5	2.1
	45°/45°	108.4	40.9	26.1	32.8	4.6	2.1	107.0	25.7	13.2	21.1	4.9	2.2
	60°/60°	102.4	38.6	24.7	34.2	6.8	3.9	100.8	24.3	12.5	24.8	5.0	2.7
	90°/90°	75.2	28.4	18.2	43.4	13.7	8.5	74.8	17.8	9.2	38.6	8.3	4.6

Table 1. EM simulation results of Diagonal SL and DTL (based on opposite current direction) at reference orientation and evaluation results of the coil-orientation effect with different angle rotations (15°, 30°, 45°, 60° and 90°) about the x-axis and/or y-axis at different distances from the coil. Comparison criteria are the mean of B1-values (which give information about the B1-intensity profiles) and the standard deviation of B1-values

(which give information about the B1 radial-uniformity).

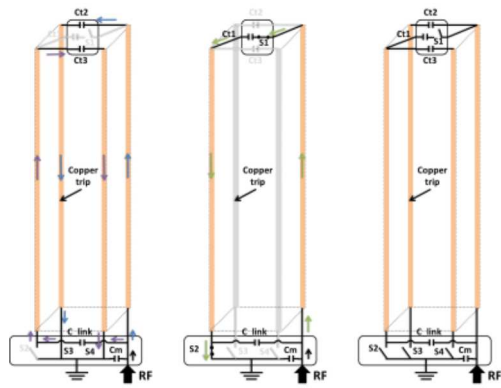


Figure 3. On the left-hand side, the proposed coil-design circuit based on two loop-configurations. This design allows to ensure the active decoupling during MR radio-frequency transmission by opening all switches (no loop-coil). On the center-middle side, by closing only S1 and S2, the SL coil is activated (tuned by Ct1 and matched by Cm//C_link). On the right-hand side, by opening S1, S2 and closing S3, S4, the SL coil is transformed in to a DTL coil with opposite current direction (tuned by Ct2, Ct3, C_link and matched by only Cm).