Self-Resonant Swiss Roll Structures as Semi-Active Device Visualization Method for Interventional MRI

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Target Audience

This paper is addressed to physicians and scientists who are active in the field of interventional magnetic resonance imaging (iMRI) as well as manufactures of instruments needed for performing these interventions. Clinical applications could be MR guided interventions like percutaneous biopsies, tumor treatment or intravascular interventions.

Purpose

MRI is well suited as guiding modality for minimal-invasive interventions due to its superior soft tissue contrast and the opportunity of arbitrary slice positioning. In order to enable a precise positioning of the instrument, suitable visualization techniques are necessary. Resonant markers (RM), tuned to the larmor frequency, are a much-examined method for visualizing the instruments tip. However, the majority of the publications deal with wire-winded coils tuned with bulky discrete capacitors, which are therefore not suitable for clinical applications. Hence, this paper examines the applicability of so-called swiss rolls[1] as a self-resonant semi-active visualization method.

Methods

Two different foils were used for the fabrication of the swiss roll structure: a PI-laminated copper foil (thickness Cu 35µm; PI 23µm) and an oxidized aluminum foil (thickness 15µm). With the oxidation process an isolating Al_2O_3-layer with an adjustable thickness can be generated. Trapezoid-shaped foil strips were wound around a polymer tube (Ø 7,5mm). Electrical characterization was examined by two-port inductive coupling to a vector network analyzer. The entire RM was housed by applying a heat shrinking tube in order to obtain full waterproofing. Visibility tests were realized inside a wide-bore 3T MR Scanner using a water phantom. The resonant markers were orientated perpendicular to B_0 in order to obtain a maximum coupling of the B_1 field. A T1w FLASH sequence was applied (TE/TR=3/10ms, FA=1°, square 180mm FOV, matrix 160x160, slice thickness 3mm). The contrast-to-noise ratio (CNR) of the excited spins (min. 300% of background signal) in the vicinity of each resonant marker has been calculated.

No.	foil	f_{res} [MHz]	Q	CNR
1	laminated Cu foil	119,45	40	648
2	laminated Cu foil	120,35	41	683
3	laminated Cu foil	124,50	44	1056
4	oxidized Al foil	122,35	91	1467
5	oxidized Al foil	122,50	77	1583
6	oxidized Al foil	122,50	57	1230

Tab. 1: Results of the electrical characterization and determined CNR

Results

Tab. 1 shows the results of the electrical characterization and the determined CNRs. All RM were tuned approximately to 123,2MHz. The CNR depends directly on the Q factor. Higher CNR can be achieved with the oxidized foils.

Fig. 1 summarizes the sections of the MR images showing the RM1-6. RM4 and RM5 lead to significant signal amplification outside the tube, which is 20-30 times higher than the background signal.

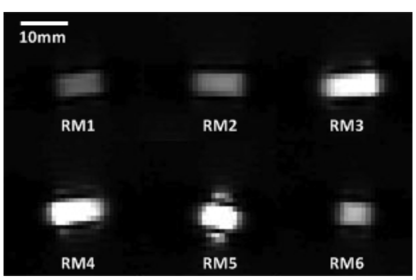

Fig. 1: Sections of MR images with RM1-6

Discussion

The results show the applicability of self-resonant swiss rolls as a semi-active visualization method. However, the achieved Q factor was too high. This leads to artifacts in cases of flip angles higher than 5°. Thinner metallic layers would increase the ohmic resistance and, thus, decrease the Q factor. Besides, lower resonant frequencies and smaller geometrical dimensions of the entire MR marker could be realized with thinner foils.

Conclusion

The swiss roll as a self-resonant semi-active visualization method has been proven to be a suitable technique for visualizing the tube tip. However, the geometrical dimensions of the used polymer tubes are relatively large. Hence, the aim is to adapt this principle to other instruments such as introducers, catheters, needle holders and biopsy needles. Furthermore, the presented RM can be used as landmarks for correction of patient motion.

References

1. Pendry JB, Holden AJ, Robbins DJ, et al. Magnetism from conductors and enhanced nonlinear phenomena. IEEE T Microw Theory. 1999;47(11):2075–2084.