Loopless antenna with improved distal sensitivity and tapered whip insulation

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Introduction

A loopless antenna designed based on an unbalanced dipole antenna [1] is ideal for minimally invasive applications because of its easy implementation, miniaturization, and high near-field SNR [1]. One major limitation of the loopless antenna receiver is that its sensitivity profile gradually falls off to zero along the antenna whip [2] with the highest SNR concentrated at the junction area and the lowest SNR at the distal end, which makes the distal section of the antenna practically invisible. Coiling the distal end of the antenna is a practical solution, but this causes increased dimensions, which is unsuitable for applications where a very low-profile tip is required. In this study, we attempted to improve the sensitivity on the distal end by adding tapered coatings along the whip of the antenna, so the current is more uniformly distributed along the whip, which makes the antenna distal end more visible during imaging, thus enhancing its tracking performance as a minimally invasive device for applications where the accurate visualization of the tip is important.

Methods

Various loopless antenna designs were simulated using an electromagnetic field solver (FEKO; EM Software & System-S-A Ltc, Version 9.1.84) to identify the effects of the various coating thicknesses on the whip current distribution, since the current is directly related to sensitivity along the antenna. The models for the simulations were set up in the following way: the antennas were assumed to operate at 63.8 MHz (1.5T), an antenna whip length of 130mm, a whip diameter of 0.1mm, an outer conductor length of 160mm, an outer diameter of 0.23mm (r_outer = r_inner *exp(50Ω/60)). The loading body was modeled as an infinite water substrate with ε_r=75, μ_r=1, δ=0.8 (assuming 0.9% saline solution). The entire whip section as well as the 80mm of the outer conductor was immersed under water. The model was excited at the junction between the whip and outer conductor with a 1 V voltage source. Based on these values, three sets of simulations were carried out: case 1, bare whip (no coating added); case 2, 0.2mm uniform coating with ε_r = 2 was added to the whip; and case 3, tapered coating from 0.2mm to 0 with ε_r = 2 was added to the whip. The current distribution in Amps was recorded along the whip with FEKO (See Figure 1).

After the FEKO simulations, three loopless antennas of the same length were constructed. These loopless antennas were created using gold-plated Nitinol wires (d = 0.203mm) for the inner conductor and Nitinol hypo tubing (d = 0.597) as the outer conductor (Nitinol Device & Components, Fremont, CA). Polymide tubings (diameter 0.0359mm) were used for the insulation between the inner and outer conductors. The outer conductors length for all three antennas were 48 cm and whip length was 8 cm. Polyester micro heat shrink tubings (Advanced Polymer INC., Salem, NH) was used for the coating on the antenna whip. The first antenna was left with a bare whip as in case 1 in the simulation; the second antenna had a uniform coating of 0.36mm on the whip; and the third antenna had a 0.36 mm to zero proximally tapered coating added to its whip. The tapering profile of the Polyster heat-shrink coating was created by heatshrinking 10 tubings of length linearly reduced from 8 cm to 1 cm. The antennas were matched and tuned to 50Ω at 63.8 MH. A 0.9% saline phantom was created for the loading. The MR imaging was carried out on a 1.5T MRI scanner (GE Medical Systems, Milwaukee, WI) with a fast gradient echo sequence (TE = minimum, TR = 68ms, BW =31.4kHz, FOV=21cm, slice thickness = 3mm, matrix = 128x128, NEX=1).

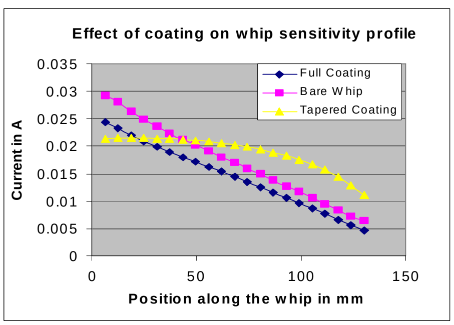

Figure1. Sensitivity profile on three antennas obtained from FEKO simulations.

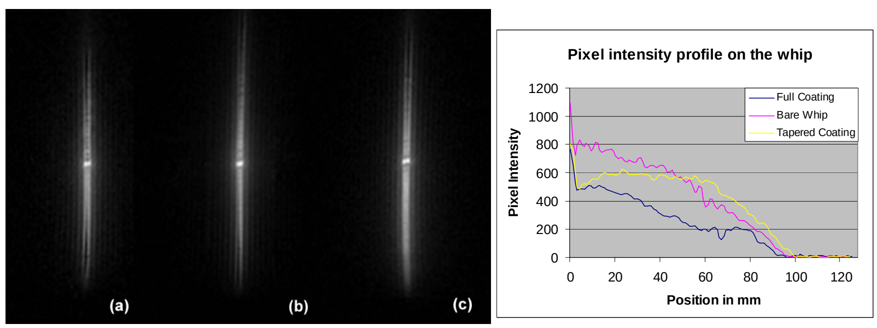

Figure2. Left: Imaging acquired on three loopless antennas with A) Full coating on the whip, B) Bare whip, C) Taper coated whip. Right: Pixel intensity measured from the images along the whip.

Results

The simulation results are shown in Figure 1. It can be seen that the current distribution for the bare whip and the uniformly coated whip had the same decreasing pattern. The uniformly coated whip had a lower overall sensitivity than the bare whip due to its non-optimal whip length [3]. The decreasing current profile on the tapered coating antenna is less dramatic. The dielectric constant of the whip coating (ε_r=2) is much less than its surrounding body (ε_r=75). Since material of higher ε_r causes more charge accumulation than lower ε_r, at sections where the coating is thick, the overall ε_r value is low, so less charge accumulation occurs, and consequently the change in current is minimal; near the distal end of the whip where coating is thin and the overall ε_r value is high (close to body ε_r values), more charge accumulation is expected. Since the distal tip is an open circuit, the current inevitably becomes zero at this point, and, from the distal tip back toward the junction of the antenna, the increase in current magnitude becomes more rapid than the fully-coated or bare wire cases. Combining these two effects with the knowledge that the current profile on the wire is directly related to the sensitivity profile, the overall sensitivity profile of the antenna becomes more uniform with the tapered insulation. The results from the experiment (see Figure 2) confirm the pattern observed in the simulations. The taper-coated antenna has a higher distal sensitivity on its whip, a visible tip and longer effective length than the other two coating configurations.

Conclusion

In this study we have successfully developed a loopless antenna with a more visible distal section on the antenna whip and a longer whip effective length. These properties are important for minimally invasive applications using MR.

Acknowledgments

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