The 3T Loopless Antenna: SNR Triples Compared to 1.5T, Heating Suppressed

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Introduction: The loopless antenna is comprised of a coaxial cable with an extended $\lambda/4$ dipole portion. It is easily miniaturized and made mechanically flexible for interventional MRI at 1.5T. Its key advantage is its high local SNR which offers great promise for imaging atherosclerotic plaques and identifying target neuronal sites for deep brain stimulation (DBS). The potential for realizing even higher SNR for such applications now exists at 3T. However, workable 3T internal antennae are unavailable, and the associated SNR gain of loopless antennae at 3T is not known. Moreover, the specific absorption rate (SAR) quadruples at 3T vs 1.5T raising major concerns about heating, while adequate antenna decoupling is essential before SNR can even be measured. In this study, we resolve the decoupling/heating issues, and determine whether the SNR of 3T loopless antennae is better than at 1.5T. SNR is compared both experimentally and using numerical EM field analysis up to 5T. Biocompatible devices are fabricated, heating and SNR are tested.

Methods: Loopless antennae constructed from $\lambda/4$ semi-rigid copper coaxial cable (2.2 mm OD) with teflon dielectric and a protruding $\lambda/4$ antenna whip (0.5 mm OD), were simulated at MRI frequencies from 0.5T to 5T using FEKO EM Software (Stellenbosch, South Africa). Because a $\lambda/4$ antenna is too short for intravascular applications at 3T, a 3T $3\lambda/4$ antenna was also simulated. The antennae were excited with a 1A current. The circularly polarized RF field, $|H^+|$ was calculated and used to compute absolute (not normalized) SNR [1]. The SNR values 1cm from the junction was used for determining field-dependence.

Experiments were conducted on 4 semi-rigid copper coax based antennae ($\lambda/4$ at 1.5T; $\lambda/4$ and $3/4\lambda$ at 3T; and $\lambda/4$ at 4.7T) with the same geometries and sample load as simulated. The antennae were tuned and matched to 50Ω. Loopless antennae were decoupled during RF transmission by imposing a short circuit condition at the cable input using a switching diode, which induces high impedance at the whip end. Heat tests were conducted with medical grade 3T loopless antennae at a scanner-reported average SAR of 10W/kg applied for 10 min, during which time temperature was monitored with fiber optic probes (FISO, Quebec CA).

The SNR of the 3T probes was measured on a Philips 3T scanner under fully-relaxed conditions at the antenna junction (GRE; TE=6 ms; FA=90; BW=31.25 KHz; NEX=1; FOV=8 cm; Matrix=256; 3mm slices). The 1.5T probe was scanned in the same phantom on a GE 1.5T scanner with the same MRI sequence. The 4.7T probe was scanned on a 4.7T Bruker scanner with same loading condition and the equivalent scanning parameters. The noise figures of all three scanner systems were measured and used to account for the system noise. The unfiltered raw data were saved for the SNR analysis. The average system-corrected SNR at each field strength was measured at 1cm from each antenna.

Finally, in vivo images for both 3T and 1.5T medical grade loopless antennas were acquired in a rabbit aorta with comparable experimental setups to compare their SNR performance and prove safe operation.

Results: The experimental SNR of the 1.5T and 3T antennae agreed with the computed SNR within 10% (Fig. 1), indicating that the experimental probes were performing near optimally for their respective geometries at each field strength. The simulated and experimental SNR for $\lambda/4$ and $3\lambda/4$ coils at 3T were also the same. Thus, longer 3T loopless antenna can be made at $3\lambda/4$ without degrading SNR. Importantly, both calculated and measured SNR showed that the 3T antennae have 3.0 (±0.3 SD)-fold better SNR performance than 1.5T antennae. The computed SNR from 0.5 T to 5T and experimental data are best fitted to $B_0^{7/4}$ (Fig 2). The decoupling circuit kept temperature increases below 1 °C, compared to a 7°C temperature rise without decoupling. In vivo experiments confirmed that 3T loopless antenna could be safely used and deliver ~3 fold the SNR performance compared to 1.5T.

Conclusion: At 3T, the SNR of the loopless antenna increases 3-fold over 1.5 T, by both experiments and EM field analysis. As shown in Fig. 1, this approximately triples the FOV. In fact, the field dependence appears to follow the 7/4th power, consistent with conduction losses at the whip end representing the dominant noise source [2]. Thus the loopless antenna can operate safely at higher field and offers a new high-SNR platform for MRI-guided intervention.

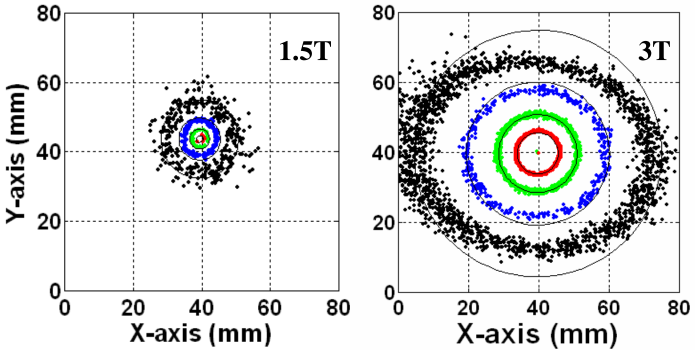

FIG. 1. Theoretical (solid) and experimental (dotted) SNR ($mL^{-1}\ Hz^{1/2}$) at junction (axial; SNR, black=20k, blue=40k, green=80k, red=160k).

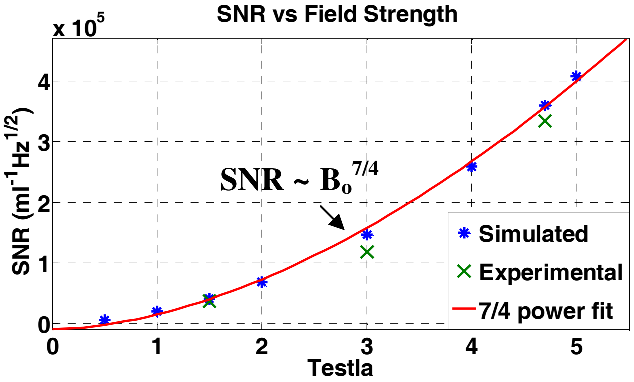

FIG. 2. Simulated (blue) and experimental SNR (green) fit to a 7/4th power law (red).

References: 1. Susil RC et al. Magn Reson Med 2003;50:383-390. 2. Hoult DI, Lauterbur PC. J Magn Reson 1979:34:425-433.

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