Investigating the Use of Carbon Nanotubes in MRI Receiver Coils

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Introduction Single-wall carbon nanotubes (SWCNT) demonstrate intriguing electrical properties that may be useful to MR coil designers. Recent literature revealed that charge transport in SWCNTs networks has minimum scattering, leading to expectations of high electrical conductivity [1]. It is thought that replacing or coating copper coils with a sufficient thickness layer of highly conductive SWCNT in RF receiver coil might enhance the coil's overall conductivity and contribute to improving the coil quality factor. As frequency increases, copper suffers from the skin and proximity effects, which negatively influence its resistance and inductance. Furthermore, Cu becomes highly sensitive to signal frequency, therefore affecting the coil's performance. Literature indicates that the skin effect in CNT bundles is significantly reduced compared to that in conventional metal conductors [2, 3], which make them attractive for high-frequency applications, specifically high-quality factor inductor design. The unique high-frequency properties of CNTs arise due to their large momentum relaxation time (leading to large kinetic inductance) [3], which causes the skin depth to saturate with frequency and, thereby, limits resistance increases at high frequencies.

Experiment Our first experiment involves three coils: solenoidal, small loop and surface coils as shown in Figure 1. The idea of replacing copper with CNT was implemented in two surface coils. While the idea of coating copper with CNT was also implemented in two solenoidal and two small loop coils. From these types, we constructed total of nine coils as listed in Table 1. Two different CNT compositions, CNT-1 and CNT-2 were used for this test, so we can compare their performance. The electrical properties of the CNT and copper surface coils were measured using a *4395A Impedance Analyzer* (Agilent, Santa Clara, CA). The three soledoidal coils were tested in an 11 Tesla Bruker NMR machine (Bruker-BioSpin, Billerica, MA) with H_2O and deuterium oxide (heavy water) D_2O samples exhibiting Larmor frequencies of 500 MHz and 76.768 MHz, respectively. These coils were also tested using the impedance analyzer. The three small coil loops were tuned and tested at 64.76MHz.

Table 1

	Solenoidal	Small loop	Surface
copper	18 G Bare flattened Cu wire	14G Bare flattened Cu wire	36 µm Cu trace
CNT-1	18 G Bare flattened Cu wire coated w/10µm CNT-1	14G Bare flattened Cu wire coated w/ 15µm CNT-1	10 µm thick CNT-1 trace
CNT-2	18 G Bare flattened Cu wire coated w/10µm CNT-2	14G Bare flattened Cu wire coated w/ 15µm CNT-2	10 µm thick CNT-2 trace

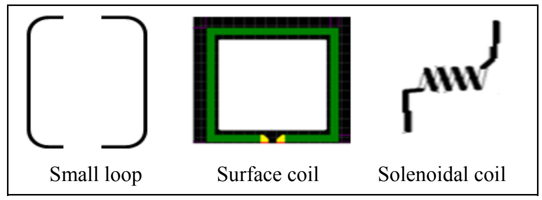

Figure 1. Selonoidal, surface and small loop coils.

Results and conclusion The measured DC resistance of the CNT-1 and CNT-2 Surface coils is 754 KΩ and 351.7 KΩ, respectively, while the DC resistance of the Cu coil is in the mΩ range. As we increase frequency, the resistance and impedance of the copper coil increases due to the skin effect, while the resistance and impedance of the CNT-1 and CNT-2 coils decreases as illustrated in Figure 2 and Figure 3, respectively. This should confirm that CNTs do not suffer from the skin effects from similar Cu wire. Furthermore, the resistances of the CNTs coils decrease as the frequency increase and approach that of Cu coils at 300MHz. The CNT coils demonstrate a comparatively small inductance that is lower than the noise floor of the analyzer.

The test results show no significant differences in inductance, impedance, or quality factor among CNT-coated and Cu solenoidal and small loop coils. By coating copper with a CNT layer, we created two parallel paths for the current, one with high resistance (CNT) and another with low resistance (Cu). Obviously, the current will flow in the low resistance path; therefore, coating copper coil with highly resistive CNT would not affect the copper coil performance.

The use of CNTs in the construction of RF receiver coils appears to hold promise. CNT traces demonstrate complete absence of skin and proximity effects. In fact, their resistance decreases with frequency. The primary shortcoming found in these samples of CNTs is the high DC resistance. Variations in the CNT composition, deposition method, coil geometry, and structure should be investigated to overcome this hurdle.

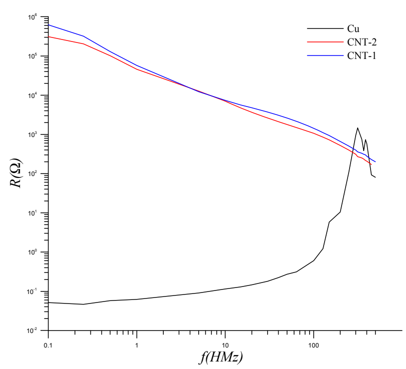

Figure 2. Resistance vs. frequency for surface coils.

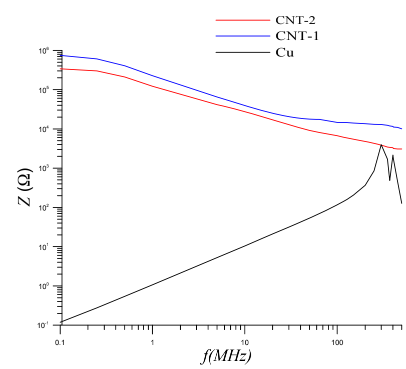

Figure 3. Impedance vs. frequency for surface coils.

References

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