Can Litz Coils benefit SNR in Remotely Polarized MRI

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Introduction: There are a number of applications for low field MRI, including hyperpolarized gas MRI, hyperpolarized C13 or PHIP, and prepolarized MRI. Unlike conventional MRI, there is no SNR advantage to increased field strength above the so-called body noise dominance threshold [1, 2]. It is critical to choose the most sensitive RF coil for low field MRI. It is well known that litz wire is more sensitive than solid copper up to 1 MHz [3]. Here we investigate litz wire for resonant frequencies up to 10 MHz.

Theory: The term litz wire describes a conductor consisting of separately insulated strands twisted or woven together in such a way that all strands pass through all points within the conductor. This forces the current to be evenly distributed among the separated strands, thus reducing eddy current losses. The AC resistance per unit length of a litz wire segment is given in [4], where the functions *F(x)* and *G(x)* describe the losses due to skin effect and proximity effect respectively.

$$R_{ac} = R_{dc} \cdot \left[\frac{1+F(x)}{s} + \frac{2 \cdot s \cdot d^2}{D^2} \cdot G(x) \right] \qquad x = \frac{d}{\sqrt{2} \cdot \delta}$$

R_{dc}	direct current resistance of a single strand
s	number of strands
d	diameter of a single strand
D	overall diameter of the litz cable
δ	skin depth (dependent upon frequency)

For a given cross-sectional area (fixed *D*) and frequency two variables need to be optimized: First, the strand diameter *d* should be chosen to be smaller than a skin depth. Once the strand size is selected, the strand number *s* needs to be optimized since there is a minimum in the AC resistance for each specific frequency (see Figure 1).

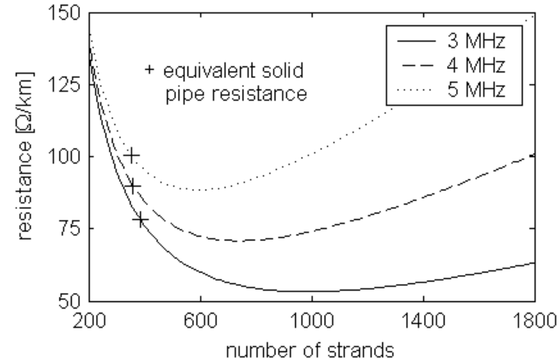

Figure 1: AC resistance simulation of AWG 48 litz wire (*D* = 74 mils) versus strand #. Note minimum resistance for each frequency. Optimal litz wire resistance is 32% less at 3 MHz, 21% less at 4 MHz and 12% less at 5 MHz than solid pipe resistance.

Methods: To validate this theory for MRI applications, we constructed two 3” diameter, 4 turn surface coils (see Figure 2). The solid coil consisted of 5 mils thick by 74 mils wide copper foil. The litz coil was made from *D* = 74 mils, 1725 strand AWG 48 litz wire. The coil Q measurements (Q_m, obtained on HP 3589A) and computed predictions (Q_c) were compared.

Results: Measured and computed Q factors are given in Table 1. Although predicted Q exceeds the measured Q, the results agree once the estimated capacitor Q of 2500 is included.

	f = 1.35 MHz		f = 2.7 MHz		f = 3.8 MHz	
litz coil	Q_m = 513	Q_c = 658	Q_m = 432	Q_c = 525	Q_m = 328	Q_c = 414
foil coil	Q_m = 110	Q_c = 124	Q_m = 157	Q_c = 175	Q_m = 176	Q_c = 208
SNR increase	2.2		1.7		1.4	

Table 1: measured and calculated Q factor for various frequencies.

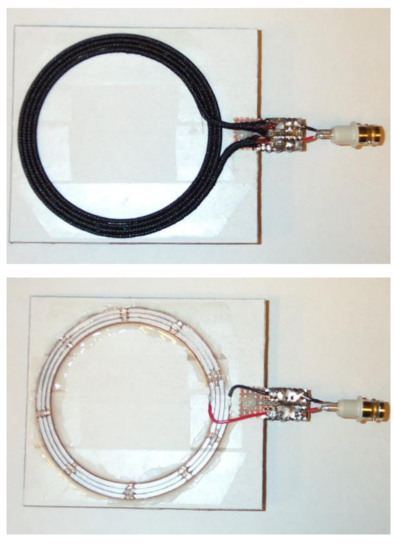

Figure 2: 4-turn litz wire coil and 4-turn copper foil coil. Despite the fact that the used litz wire is optimized for 1.7 MHz, it still increases SNR by a factor of 1.4 at 3.8 MHz. At 1.35 MHz the SNR increase is 2.2.

Discussion: We found that Butterworth’s theory [4] was accurate for predicting the Q of a litz coil. The litz performs better versus the foil design of similar geometry and construction to 4 MHz, despite the fact that we used litz wire optimized for 1.7 MHz. Moreover, the theory indicates that litz coils can be designed even up to 10 MHz. For example, 1500 strands of AWG 52 should have 50% the resistance of solid copper at 8 MHz (*D* = 74 mils). The theory demonstrates that for any solid pipe diameter, a litz construction of same cable diameter can be constructed with lower RF losses subject to strand diameter limits of 60 AWG. Traditional litz cables optimized for power applications attempt to minimize both DC and AC losses. However, litz construction for MRI coils will benefit from constructions minimizing only RF losses. Low field applications like prepolarized MRI, hyperpolarized gas or PHIP could greatly benefit from a more optimized litz wire construction.

References:

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