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Quality factor measurement and enhancement techniques for ultra-high field surface loop receiver coils

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Hypothesis Quality ratio (Q_R), calculated from the ratio of unloaded (Q_U) to loaded (Q_L) quality factor of a resonant coil element, as measured on the bench, can be used to estimate the fraction of the ideal SNR obtained from MRI measurement according to the following equations:

$$SNR = SNR_{ideal}\sqrt{1-\frac{1}{Q_R}} \quad \{1\}$$

$$Q_R = \frac{Q_U}{Q_L} \quad \{2\}$$

$$Q_U = \frac{X_{coil}}{R_{coil}+R_{rad}} \quad \{3\}$$

Figure 1. Decoupled Double B-field probe

$$Q_L = \frac{X_{coil}}{R_{coil}+R_{rad}+R_{sample}} \quad \{4\}$$

Methods We validate HFSS simulations of Q-ratio to measurements made on the bench with a >60 dB decoupled double B-field probe (Figure 1) of various resonators described in Table 1.

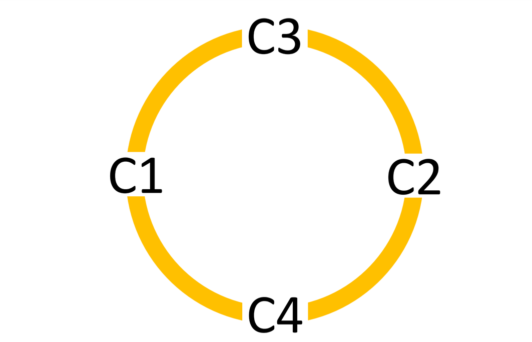
B_0	Diameter	Conductor	C_1 pF (Q)	C_2 pF (Q)	C_3 pF (Q)	C_4 pF (Q)
7T	21 mm	15 AWG	8.2 (1000)		$R_{ESR} = \frac{1}{\omega CQ}$ {5}	
	42 mm	15 AWG	3.3 (400)			
	62 mm	15 AWG	3.3 (400)	3.3 (400)		
	85 mm	15 AWG	4.7 (400)	4.7 (400)	4.7 (400)	4.7 (400)
10.5T	12 mm	15 AWG	8.2 (500)			
	21 mm	15 AWG	1–12 (450)			
	45 mm	15 AWG	2.7 (900)	2.2 (1000)		
	40 mm	2 mm PCB	1.0 (2000)			
	62 mm	15 AWG	1.8 (300)	1-23 (300)		
	85 mm	15 AWG	2.7 (300)	2.7 (300)	2.2 (350)	2.2(900)

Table 1. Resonators measured on the bench and simulated in HFSS for Q-ratio.

Results from measurements of Q-ratio on the bench and in simulation are documented in Fig 2 with Simulated radiation resistances (R_{Rad}) in Figs 3&4. Practical coil Q-ratios are plotted in Fig 5 with simulated SNR compared to experimental SNR for a 128-channel coil [10] in Fig 6.

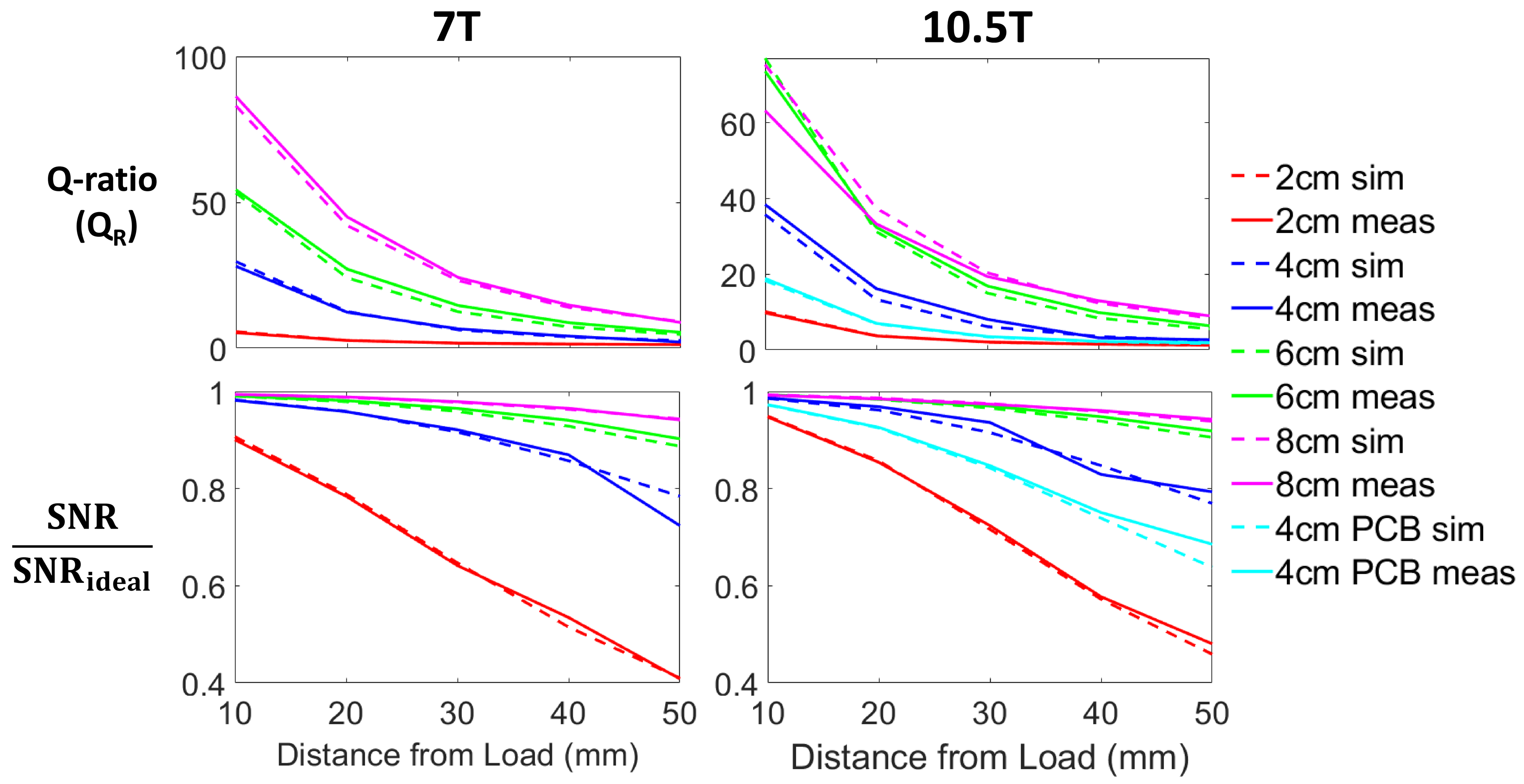


Figure 2. Resonators measured on the bench and simulated in HFSS for Q-ratio (eq {2}) and fraction of ideal SNR (calculated from eq {1}).

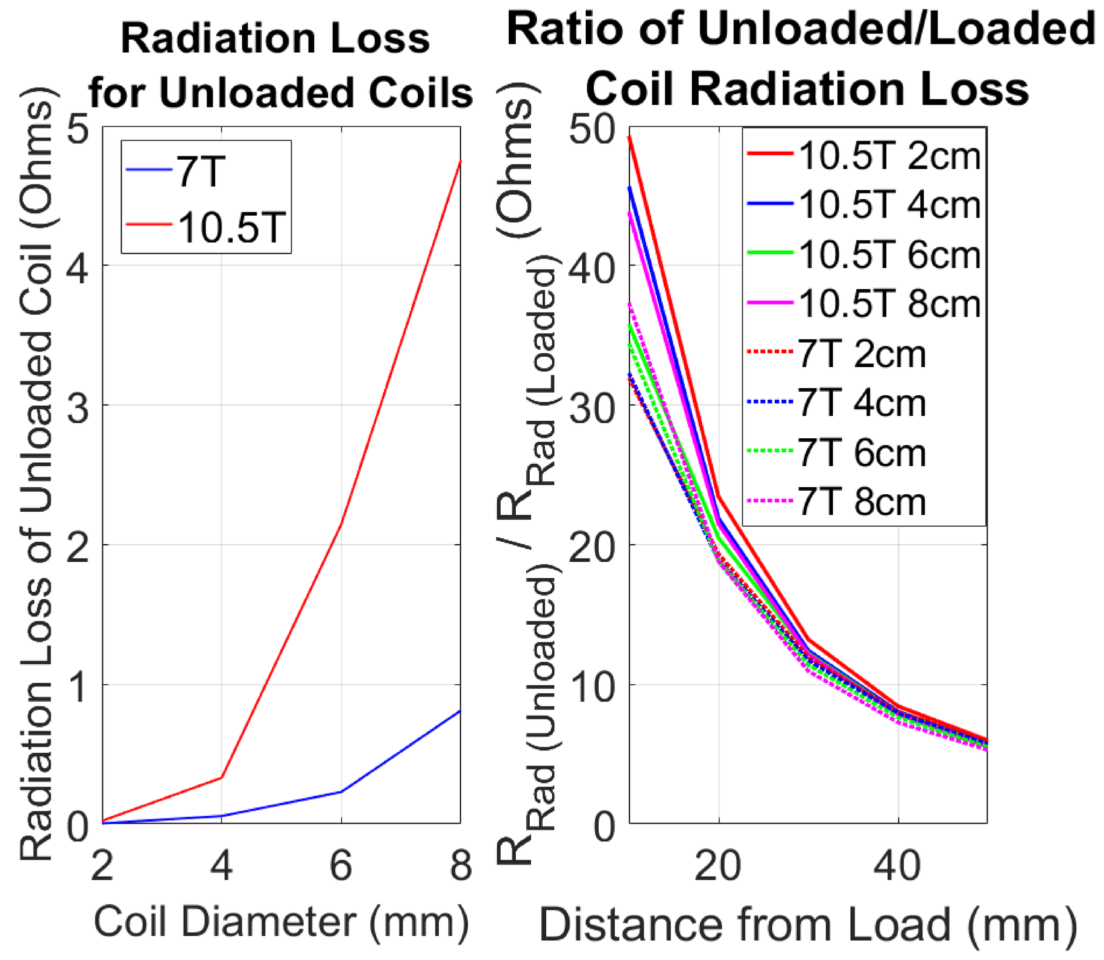


Figure 3. Radiation Losses (R_{Rad}) as a function of coil diameter, frequency, and load distance.

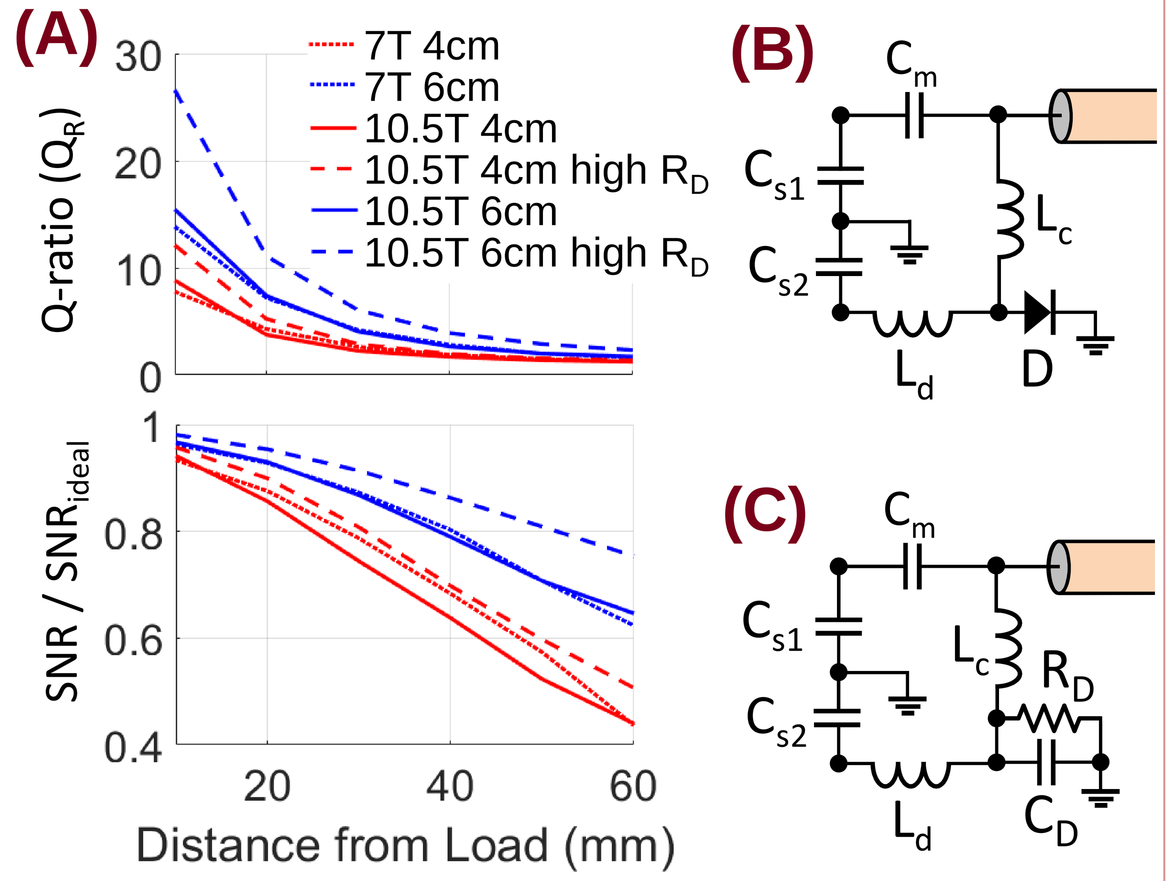


Figure 5. (A) Q-ratios of practical RF coils with feed circuit shown in **(B)** with equivalent circuit **(C)**.

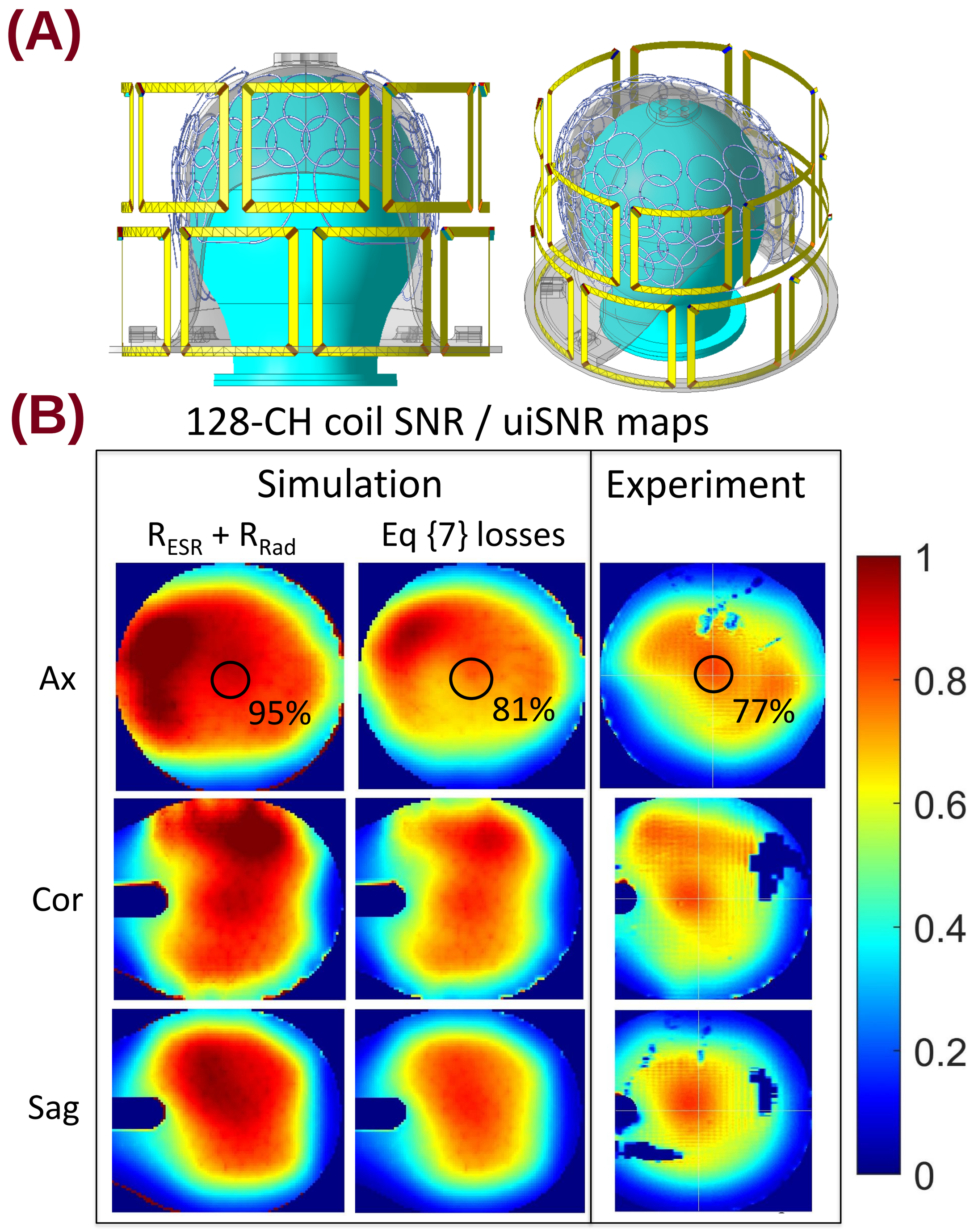


Figure 6. (A) HFSS model of 128-channel 10.5T coil [10] with **(B)** simulated vs experimental SNR/uiSNR maps showing the importance of accounting for all coil losses shown in eq {7}.

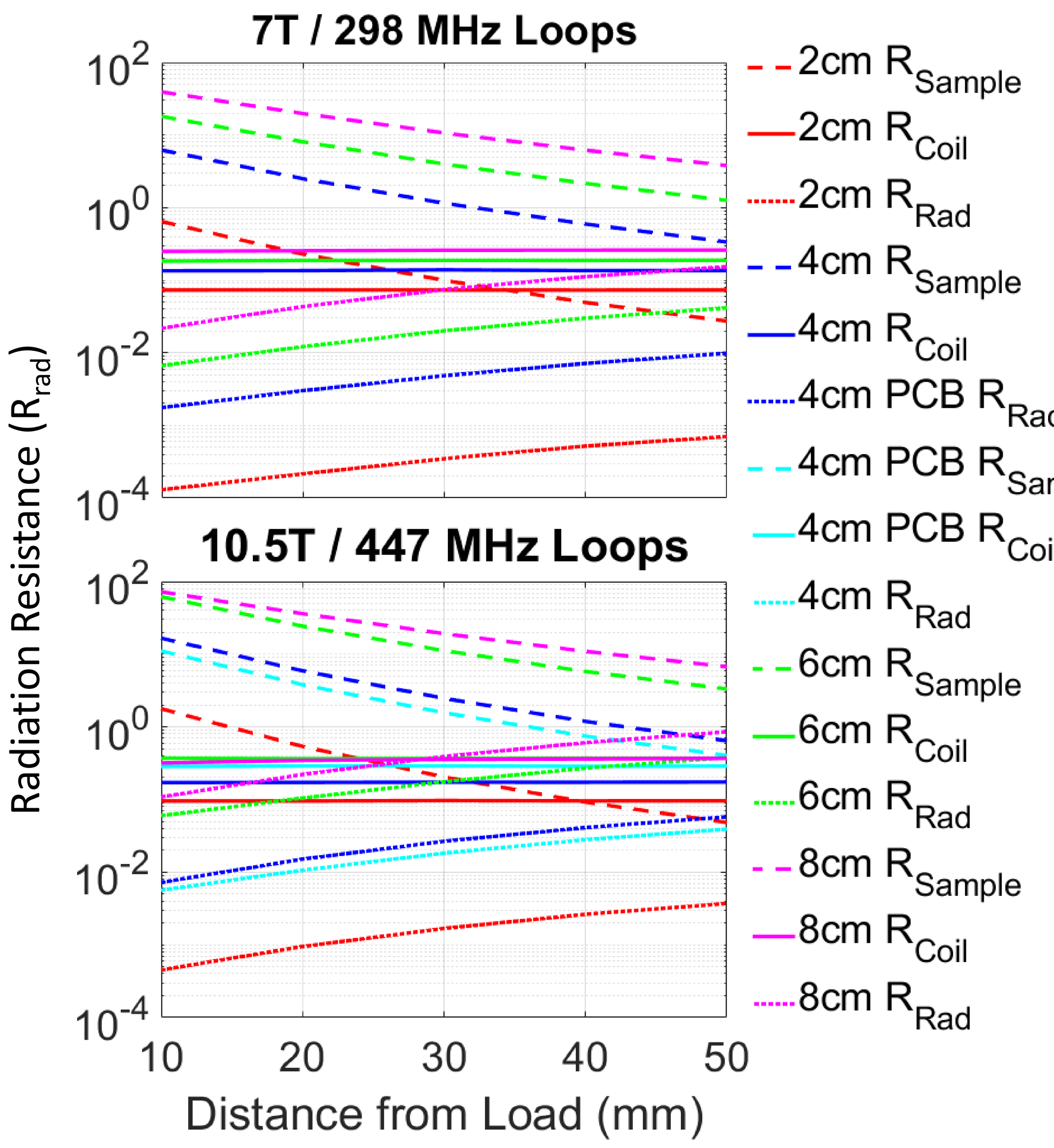


Figure 4. Simulated resonator resistance values R_{Coil}, R_{Rad}, and R_{Sample} referenced in eqns {3} and {4}.

Outcomes

1. Measurement of Q_U should be made in proximity to a conductive sheet (proposed by [15]) to reduce R_{Rad} which is significant at high field as shown in Figs 3 & 4.

2. Detune circuit parasitics, such as R_{Detune} (calculated from C_{s2} & R_D in Fig 5 using eq {6}), significantly reduce Q-ratio as shown in eq {7}:

$$R_{Detune} \approx \frac{1}{(\omega C_{s2})^2 R_D} \quad \{6\}$$

$$Q_L = \frac{X_{coil}}{R_{coil}+R_{rad}+R_{sample}+R_{Detune}} \quad \{7\}$$

3. Accurate simulation of SNR (Fig 6) must account for all coil losses: R_{ESR}, R_{Rad}, R_{Coil}, and R_{Detune} all of which can be measured with Q-ratio, as shown in eq {7}.

GitHub repository with Q-ratio data & PDF of poster:

References

[1] Vaughan JT, et al. MRM 2001;46(1):24-30 [2] Pohmann R, et al. MRM 2016;75(2):801-809 [3] Ocali O, Atalar E. MRM 1998;39(3):462-473 [4] Uğurbil K. Neuroimage 2018;168(7-32) [5] Dumoulin SO, et al. Neuroimage 2018;168(345-357) [6] Duyn JH, et al. PNAS 2007;104(28):11796-11801 [7] Budde J, et al. MRM 2011;65(2):544-550 [8] Vaidya MV, et al. Concept Magn Reason B 2014;44(3):53-65 [9] Waks M, et al. MRM 2025; 93: 873-888 [10] Lagore RL, et al. MRM 2025; 93: 2680-2698. [11] Hayes CE, Axel L. J. Med. Phys. 1985;12(5):604-607 [12] Kumar A, Edelstein WA, Bottomley PA. MRM 2009;61(5):1201-1209 [13] Webb A, O'Reilly T. MAGMA 2023;36(3):375-393 [14] Gruber B, et al. MRM 2023;90(6):2592-2607 [15] Chen G, et al. MRM 2018 Mar;79(3):1773-1780.

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