LOW-LOSS TUNING AND MATCHING CIRCUITRY FOR HTS BASED RF MRI COILS AND ARRAYS

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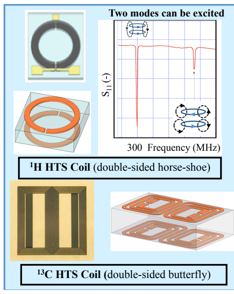
Introduction

- **Magnetic resonance resonators utilizing either cold Cu or HTS materials have demonstrated for certain MRI and NMR applications very significant gains in signal-to-noise ratio (SNR) [1-4].**
- **Total loss in the MRI system consists of coil, body (either phantom or extracted organs and/or animal), cryostat, and electronics (tuning/ matching/decoupling circuitry) losses. We have developed low-loss, receive-only frequency tuning and impedance matching circuitry using capacitive coupling of the circuit to the coil. We used nonmagnetic varactors or nonmagnetic mechanically adjustable cryogenic capacitors [5-6].**
- **By analyzing the loss mechanisms associated with tuning and matching we have obtained a sufficient tuning range in HTS-based probes without a decrease in Q. Almost 2000 high $Q_{electronics}$ was achieved.**
- **Cryogenic and especially superconducting receive coils potentially can provide very significant SNR gain for ^{13}C detection at 7 T (much larger than for ^{1}H), due to 4 times lower Larmor frequency than for protons and resulting lower body loss (proportional to frequency square) [7].**

Objective: to design and optimize a cryogenic (both Cu and HTS) ^{1}H (300 MHz) 7 Tesla receiver probe form maximum of SNR gain. Low loss tuning/ matching and decoupling circuitry is compatible with closed-cycle pulsed tube cooling system and 72 mm transmit Bruker volume coil [8].

Coils and Circuitry Designs

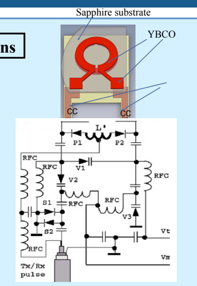


^{1}H HTS Coil (double-sided horse-shoe)

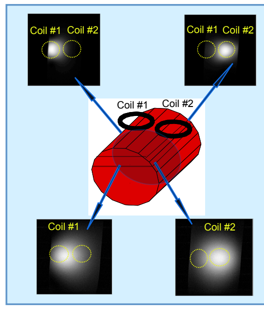
^{13}C HTS Coil (double-sided butterfly)

The Cu coil and electronic circuit layout were patterned using LPKF PhotoMat C100.

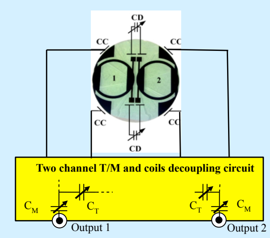
For superconducting coil, **YBCO** films deposited on both sides of a 0.33 mm thick Al_2O_3 (ε=10.4) wafer were patterned using optical lithography and wet etching.



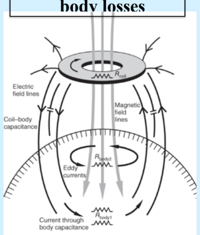
Tuning/Matching (T/M) Circuit

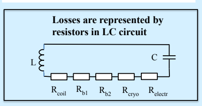


$$\frac{Array\_SNR}{Single\_Coil\_SNR^{300K}} = \sqrt{\frac{1+\delta+\gamma}{1/N+(\alpha\beta\cdot\delta+\gamma\cdot N)N}}$$



Sources of the coil-body losses





Cryo-coil maximum size calculations. SNR Gain for ^{1}H and ^{13}C

$$Q_{total} = \frac{\omega L}{(R_{coil}+R_{electronics}+Q_{cryostat}+Q_{body}}$$

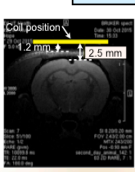
	19 mm double sided horse-shoe coil			24 mm x 34 mm butterfly coil		19 mm double sided horse-shoe coil	
Q-factor	^{1}H Cu_295K	^{1}H Cu_60K	^{1}H (17 mm) HTS_60K	^{13}C Cu_295K	^{13}C Cu_60K	^{13}C (19 mm) Cu_295	^{13}C (19 mm) Cu_60K
Coil only	360	960	29000 (7 T)	180	490	220	560
Coil+ electronics	250 (820)	670 (1520)	1650 (1600)	140 (790)	375 (1450)	170 (680)	410 (1650)
Coil+ electronics +cryostat	240 (820) (6000)	620 (1520) (6000)	1320 (1650) (6000)	135 (790) (6000)	350 (1450) (6000)	165 (680) (6000)	390 (1700) (6000)
Coil+ electronics +cryostat +body	180 (820) (6000) (920)	380 (1520) (6000) (920)	470 (1650) (6000) (1220)	125 (760) (6000) (1110)	270 (1450) (6000) (1110)	145 (680) (6000) (1550)	310 (1650) (6000) (1550)
SNR_gain over 295K Cu	---------	1.9x 5.4 dB	2.3x 7.4 dB	---------	2.1x 6.6 dB	---------	3.0x 9.3 dB

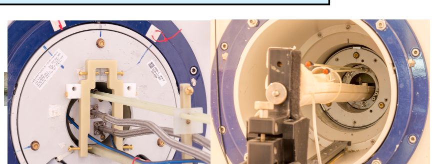
$$\alpha = \frac{T_{coil}}{T_{body}};\alpha_1 = \frac{T_{electronics}}{T_{body}} \qquad \beta = \frac{R^{55K}_{coil}}{R^{295}_{coil}}$$

$$\frac{Single\_coil\_SNR}{Single\_coil\_SNR^{295K}} = Gain = \sqrt{\frac{1+\delta+\gamma}{1+(\alpha\beta\delta+\alpha_1\gamma)}}$$

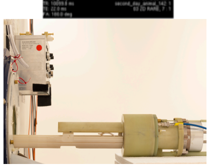
$$\gamma = \frac{R_{electronics}}{R_{body}} \qquad \delta = \frac{R_{Coil}}{R_{Body}}$$

Closed cycle pulsed tube cryo-cooler based MRI probe [9]



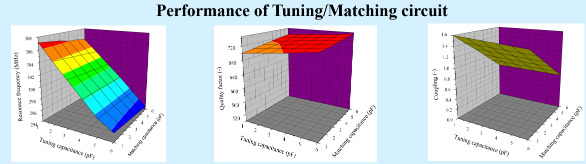


7 Tesla Bruker scanner with our cryo-probe

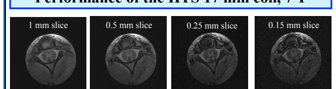


Coldhead with G-10 shroud (60 K)

Performance of Tuning/Matching circuit

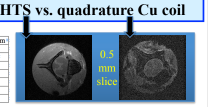


Performance of the HTS 17 mm coil, 7 T

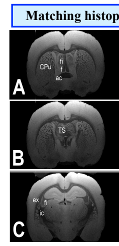


Comparison HTS vs. quadrature Cu coil

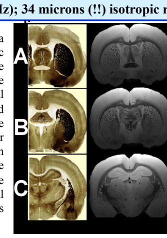
Slice Thickness	1, 0.5, 0.25, 0.15 mm
FOV	1.5cm x1.5cm
Spacial resolution	59x59 microns
Scan type	MSME
Acquisition time	13 min 20 sec
TR	300 ms
TE	13 ms
# of averages	1



Matching histopathology slices at 7 T (300 MHz); 34 microns (!!) isotropic resolution (rat brain) 3D, 256



Axial 3D-RARE images of a fixed rat brain with an isotropic resolution of 34 µm. A; The fine structures in the Caudate Putamen (CPu) or hippocampal fimbria (fi) would not be resolved at Cu coils resolutions. The fornix (f) and anterior commissure (ac) have been labeled for orientation. B; The area between the external capsule (ex), fimbria (fi), and the internal capsule (ic) contains many fibers usually not seen in MRIs.



The right column contains the MRIs A-C from the previous viewgraph. The left column contains the matching histological plates from Paxinos and Watson's Rat Brain atlas [10]. It can be clearly seen that the fiber structures displayed in the MRIs with 34µm isotropic resolution (right column) match very well what is displayed in the histological plates of the right column.

Discussion and conclusions

- **Here we demonstrate the performance of a ^{1}H receiver coil for 7 T scanner by introducing lower-loss tuning/matching/decoupling circuitry, stabilizing the operating frequency at cryogenic temperatures for very long scans (i.e. even a few days long!) and shortening the coil to body distance.**
- **Our motivation was to assess the practical isotropic resolution limit for the rat brain using very high SNR cryo-coil (up to 45,000/mm^3.**
- **Maximum Q and hence the SNR gain of the system is limited here either by body losses, for *in-vivo* small animals imaging, or by electronics losses, for *in-vitro* microscopy imaging.**
- **Effective SNR gain for cooled Cu and HTS coil over 295 K Cu, depends also very strongly on the coil-body distance as well as on flatness of the coils.**
- **^{13}C 7T (75 MHz) coil of the same diameter as ^{1}H coil, provide 300% SNR gain comparing with only 100% SNR gain achievable for ^{1}H 7T Cu coil (300 MHz).**

References

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