HTS surface coil for MRI of the patella

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Introduction.

It has already been recognized that significant SNR improvement can be achieved in small sized devices, through cooling of normal metal or by using high temperature superconductors (HTS) for coil fabrication [1-2]. SNR can be further dramatically improved with the use of transmit-receive HTS coils when inductive coupling is used. However, for receive-only coil design a capacitive coupling to each element and also de-tuning scheme have to be implemented. This is of particular concern in applications where the pulse sequence requires uniform RF excitation, such as in trabecular bone imaging with large flip angles [3], typically achieved by using the body coil for transmit and a small surface coil (having a non-uniform B_1 field) for receive. In addition, because of the relatively high Q of the coil, it is necessary that tuning/matching adjustments be performed outside the cryostat and MRI magnet. In this study, we have designed a prototype HTS receive-only single-element coil for the purpose of high-resolution MRI of the knee. By increasing SNR, it is expected that this coil will permit *in vivo* micro-imaging of patellar trabecular bone within a reasonable scan time.

Method and Results.

The coil was design to take advantage of very low dielectric loss of single crystal substrate ($LaAlO_3$) on which superconducting films are deposited. A double-sided structure was used to introduce distributed capacitance in the coil design, minimizing stray electric fields that can lead to additional dielectric loss in the sample [4-5]. Also this double-sided coil concept allows for the addition of coupling capacitors on the HTS film in order to connect matching and tuning circuit. The 0.5 µm thick YBCO films were deposited on both sides of the $LaAlO_3$ substrate by the co-evaporation method [Agile Devices, Inc.]. These films were patterned into a split quasi ring shape (47-mm outer diameter, 32-mm inner diameter and 16-mm shorter opening dimension) using standard positive photoresist and wet etching processes. The gaps on two sides of the substrate, in each quasi ring are rotated 180° from each other (Figs. 1a and 2). Despite the simple coil form, the resonant frequency of the coil has a complicated dependence on the resonant circuit elements. Such resonator can be represented as two sections of coaxial cables, where the outer and inner conductors are connected either directly or through capacitors (Fig. 1b). The matching and tuning circuit was integrated with the coil (Fig. 2) and adopted for cryogenics. By changing the applied, V_m (matching) and V_t (tuning), voltages for the GaAs varicap diodes, both 63.8 MHz tuning and 50 Ω rf coaxial cable matching can be achieved. The HTS coil used for µ-MRI of the patellar trabecular bone will be immersed in a liquid nitrogen cryostat (Fig. 3) that will be supported on a plastic frame above the knee, the superficial location of the patella being ideally suited to µ-MRI with a small surface coil. Using the FLASE pulse sequence and a 1.5 T clinical MRI scanner, a target resolution of 137x137x410 μm^3 with SNR ~ 10 is anticipated within a scan time of 5 minutes.

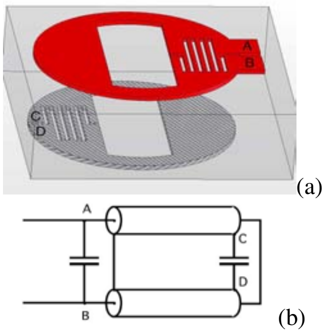

Fig. 1. (a) A sketch of the coil design. A, B and C, D show the points on left and right banks of the gaps of the two 180° rotated rings. The corresponding four points are shown in the transmission line coil model (b).

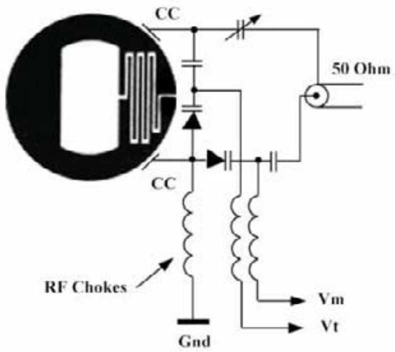

Fig. 2. A matching and tuning circuit using varicap GaAs diodes is shown. A picture of the upper side of a 47 mm YBCO superconducting coil is shown. CC denotes coupling capacitors (details are not shown).

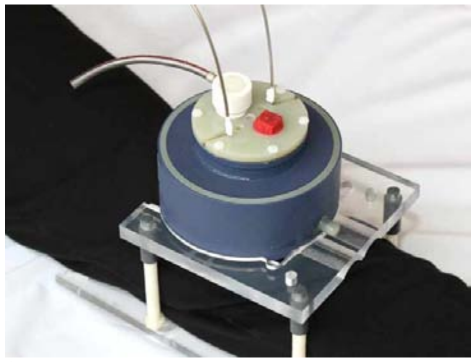

Fig. 3. A picture of the HTS coil set-up for the patella imaging. HTS coil integrated with a matching and tuning circuit and kept at 77 K (liquid nitrogen) in a plastic G-10 cryostat. A leg holder and RF and dc cables are also shown.

Discussion and conclusions.

For the system shown in Fig. 3 the inverse of total unloaded Q (Q_{tot}) is equal to $1/Q_{coil}+1/Q_{cryostat}+1/Q_{electronics}+1/Q_{body}$, where for the HTS coil Q_{coil}, $Q_{cryostat}$, and Q_{body} were 30,000, 15,000, and 2,000, respectively. The $Q_{electronics}$ was optimized via circuit modeling as shown in Fig. 2. It is can be seen from Fig. 4 that 50 Ω matching and 64 MHz tuning can be achieved at Ct=10 and Cm=4.5 Cm (CC=90pF); however, the matching/tuning circuit reduces Q_{coil} 35%. In order to estimate potential SNR gain of such coil, we measured Qs of room temperature (RT) Cu, 77 K Cu, and 77K HTS coils with and without knee loading. Using the one port Ginzton method, unloaded Q's were measured as 250, 900, 2300 for RT Cu, 77 K Cu and 77 K HTS coils, respectively. Using both unloaded and knee loaded data, we have calculated [6] SNR gain of the HTS and Cu 77 K over RT Cu coil as 80% and 50%, respectively. Such gains were confirmed from measured with a phantom (1.5 T GE scanner) SNR map for RT Cu and 77 K Cu. Further tests of the HTS coil are under way.

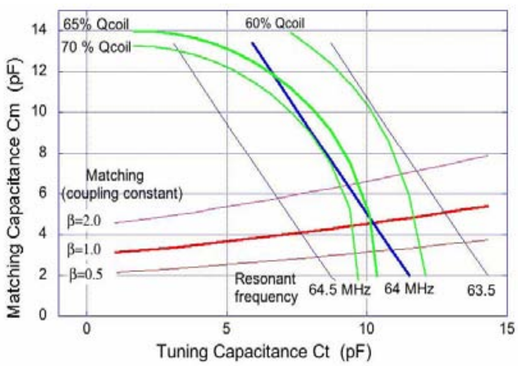

Fig. 4. Cross-sections of the F(Cm,Ct, f, β,Q) surface plot with constant values planes of resonant frequency, matching and Qs.

References

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